CONDITIONAL PROBABILITIES OF PRECIPITATION TYPES
IN THE CENTRAL TEXAS AREA AS DETERMINED BY
THERMAL PARAMETERS

APPROVED:

Norman K. Wagner
____

Lothar Kordmeader
____

DEDICATION

This thesis is dedicated to my parents who have shown me the value of an education and have taught me so many of my life's priorities. During the many years of my education they have shared both the joys and disappointments of my life. I appreciate everything they have done for me, and this thesis is a small way of thanking them.

This thesis is also dedicated to the memory of Professor Kenneth H. Jehn, who taught so many students very valuable meteorological principles during his long career at the University of Texas. He once told me he was very anxious to see my thesis results, but he never did. This thesis is a tribute to his career.

CONDITIONAL PROBABILITIES OF PRECIPITATION TYPES IN THE CENTRAL TEXAS AREA AS DETERMINED BY THERMAL PARAMETERS

BY

EDUARDO BOSCH, B.E.S.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE IN ENGINEERING

THE UNIVERSITY OF TEXAS AT AUSTIN

December 1980

ACKNOWLEDGEMENTS

My deepest appreciations go to both Dr. Norman K. Wagner and Dr. E.L. Koschmieder for the time and patience they showed during the supervising and arrangement of this thesis.

My thanks also go to David Owens, Meteorologist in Charge, of the National Weather Service in Austin for his kind help in providing me with certain necessary research materials used in this thesis, and also for his suggestions in using National Weather Service products in everyday routine forecasting of winter precipitation types. I am also deeply indebted to meteorologist David C. Grossman for all the time he took in teaching me how to forecast synoptic weather patterns.

More thanks go to Rollie C. Schroeder of the Texas Air Control Board in Austin, Texas for helping me acquire upper-level data needed for this study. I am also grateful to Gary M. Carter of the Techniques Development Laboratory for providing me with numerous Technical Procedures Bulletins that dealt with the forecasting of winter precipitation types.

For teaching me normal, routine observational procedures, my thanks go to meteorological technicians: James Dugan, Melvin Dunnigan, P.J. Lewis, Norman Putrite, and Jack Woods of the National Weather Service in Austin, Texas.

Also, my thanks go to my brothers, Silverio Carlos and José Antonio, Jr., for their advice and support of my educational quests. My thanks also go to my past secretary, Lillian Anagnos, for teaching me the basics of putting together reports in a reasonable amount of time.

Last, but not least, my thanks go to Mr. Ed. Roy of Lafayette, Louisiana for allowing me the unlimited use of his computer.

This thesis was submitted to the Supervising Committee in November of 1980.

ABSTRACT

Past winters in Central Texas are examined to determine the thickness values between atmospheric pressure levels necessary to produce rain, freezing rain, ice pellets, or snow. This is not a synoptic study of the weather systems that are conducive to frozen-precipitation occurrences in Central Texas, rather it is an objective study designed to determine the thickness values necessary for objective forecasting of these different precipitation types.

Many of the studies in the past have focused on the forecasting of rain versus snow. The thesis research not only covers this forecasting problem but also treats the intermediate types of precipitation such as ice pellets, and freezing precipitation. A number of single and joint predictors are examined. It is concluded that surface temperature and the mean temperature in the 850-1000 mb layer are most valuable in the prediction of precipitation types in Central Texas. Critical values of the various predictors for various conditional probability levels and various precipitation types are obtained.

TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
II. DATA COMPILATION & ANALYSIS	4
Data Used for this Study	4
The Necessity for Uniform Data Sampling	5
Upper-Level Height Contour Analyses	7
Determination of Hourly Values for Upper-Level Data	9
Compatibility of Sample-Data Development with Past Studies	12
Error Analysis for the Hypsometric Equation	13
Calculation of the Height of the 1000 mb Pressure Level	18
III. CLASSIFICATION METHODS USED	25
Classification of Precipitation for This Study	25
The Precipitation Classification System Used by the TDL	25
The Importance of Including Rainfall Data in the Developmental Sample	28
IV. SELECTION OF PRECIPITATION-TYPE PREDICTORS	29
V. GRAPHICAL RESULTS	31
Single Predictors: Conditional Probability Graphs and Categorical Decision Graphs	31
Joint Predictors: Sample Frequency Graphs	64
Joint Predictors: Conditional Probability Graphs and Categorical Decision Graphs	64
Joint Predictors: Sample Frequencies for Mixed Precipitation	65
Joint Predictors: Sample Frequencies for Ice Pellets (Sleet)	65
VI. DISCUSSION OF RESULTS	66
Single Predictors and Joint Predictors for Frozen Precipitation	66
Mixed Precipitation and Ice Pellets	68
Comparison with Past Studies	71
The Wagner Study of 1957	72
The Boyden Study of 1964	73
The Fortner-Roberts Study of 1971	75
The Purvis Study of 1971	80

The TDL Study of 1975 83

VII. FORECASTING APPLICATIONS OF THESIS RESULTS 85

Surface Temperature Guidance Issued by the TDL 85

Application of Thesis Results in Everyday Forecasting 89

VIII. SUMMARY 97

APPENDICES 100

BIBLIOGRAPHY 105

LIST OF TABLES

Table		Page
1.	PERIODS OF DATA USED	6
2.	THE UNCERTAINTIES IN ΔZ_{1000} RESULTING FROM INDIVIDUAL UNCERTAINTIES IN $\bar{T}*$	17
3.	CORRECTION FACTORS FOR THE STATION TEMPERATURE ARGUMENT	22
4.	PRECIPITATION CLASSIFICATION SCHEME USED FOR THIS STUDY	26
5.	SINGLE-PREDICTOR THESIS RESULTS FOR FROZEN PRECIPITATION	67
6.	SINGLE-PREDICTOR VALUES OF PRECIPITATION TYPE	69
7.	EQUAL-PROBABILITY VALUES (50%) AS DETERMINED BY WAGNER	74
8.	THERMAL PARAMETERS AS SINGLE PREDICTORS OF THE PROBABILITY OF FROZEN PRECIPITATION (SNOW) AS DETERMINED BY C.J. BOYDEN IN A 1964 STUDY FOR THE BRITISH ISLES	76
9.	THERMAL PARAMETERS AS SINGLE PREDICTORS OF THE PROBABILITY OF FROZEN PRECIPITATION (SNOW) AS DETERMINED BY LIMON E. FORTNER AND DALE G. ROBERTS IN A 1971 STUDY FOR LORING AIR FORCE BASE, MAINE	77
10.	EQUAL-PROBABILITY VALUES FOR STATIONS IN TEXAS AS DETERMINED BY THE TECHNIQUES DEVELOPMENT LABORATORY	84

LIST OF FIGURES

Figure Page

1. Example of an Upper-Level Regional Contour Analysis 10

2. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 850-1000 mb Thicknesses 32

3. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 700-1000 mb Thicknesses 33

4. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 500-1000 mb Thicknesses 34

5. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 700-850 mb Thicknesses 35

6. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 500-850 mb Thicknesses 36

7. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 500-700 mb Thicknesses 37

8. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for Surface Temperatures 38

9. Joint-Predictor Graphs of 850-1000 mb Thickness versus Surface Temperature 39

10. Joint-Predictor Graphs of 700-1000 mb Thickness versus Surface Temperature 40

11. Joint-Predictor Graphs of 500-1000 mb Thickness versus Surface Temperature 41

12. Joint-Predictor Graphs of 700-850 mb Thickness versus Surface Temperature 42

13. Joint-Predictor Graphs of 500-850 mb Thickness versus Surface Temperature 43

14. Joint-Predictor Graphs of 500-700 mb Thickness versus Surface Temperature 44

15. Joint-Predictor Graphs of 700-850 mb Thickness versus 850-1000 mb Thickness 45

16. Joint-Predictor Graphs for Conditional Probabilities for 850-1000 mb Thickness versus Surface Temperature 46

Figure | Page

17. Joint-Predictor Graphs for Conditional Probabilities for 700-1000 mb Thickness versus Surface Temperature 47

18. Joint-Predictor Graphs for Conditional Probabilities for 500-1000 mb Thickness versus Surface Temperature 48

19. Joint-Predictor Graphs for Conditional Probabilities for 700-850 mb Thickness versus Surface Temperature 49

20. Joint-Predictor Graphs for Conditional Probabilities for 500-850 mb Thickness versus Surface Temperature 50

21. Joint-Predictor Graphs for Conditional Probabilities for 500-700 mb Thickness versus Surface Temperature 51

22. Joint-Predictor Graphs for Conditional Probabilities for 700-850 mb Thickness versus 850-1000 mb Thickness 52

23. Joint-Predictor Graph for Categorical Decisions for 850-1000 mb Thickness versus Surface Temperature 53

24. Joint-Predictor Graph for Categorical Decisions for 700-1000 mb Thickness versus Surface Temperature 54

25. Joint-Predictor Graph for Categorical Decisions for 500-1000 mb Thickness versus Surface Temperature 55

26. Joint-Predictor Graph for Categorical Decisions for 700-850 mb Thickness versus Surface Temperature 56

27. Joint-Predictor Graph for Categorical Decisions for 500-850 mb Thickness versus Surface Temperature 57

28. Joint-Predictor Graph for Categorical Decisions for 500-700 mb Thickness versus Surface Temperature 58

29. Joint-Predictor Graph for Categorical Decisions for 700-850 mb Thickness versus 850-1000 mb Thickness 59

30. Joint-Predictor Graphs for "Mixed" Precipitation for 850-1000 mb Thickness versus Surface Temperature; 700-1000 mb Thickness versus Surface Temperature; & 500-1000 mb Thickness versus Surface Temperature 60

31. Joint-Predictor Graphs for "Mixed" Precipitation for 700-850 mb Thickness versus Surface Temperature; 500-850 mb Thickness versus Surface Temperature; & 500-700 mb Thickness versus Surface Temperature 61

Figure | Page

32. Joint-Predictor Graphs for "Ice-Pellet" Precipitation for 850-1000 mb Thickness versus Surface Temperature; 700-1000 mb Thickness versus Surface Temperature; & 500-1000 mb Thickness versus Surface Temperature 62

33. Joint-Predictor Graphs for "Ice Pellet" Precipitation for 700-850 mb Thickness versus Surface Temperature; 500-850 mb Thickness versus Surface Temperature; & 500-700 mb Thickness versus Surface Temperature 63

34. Comparison of Purvis' Results with Thesis Results 82

35. An Example of PoPT (Probability of Precipitation Type) Guidance 87

36. Panel C of the LFM-II Numerical Guidance Output 90

37. Panel A of the LFM-II Numerical Guidance Output 91

38. Panel B of the LFM-II Numerical Guidance Output 92

I. INTRODUCTION

The main parameter involved in determining precipitation type at any one location is temperature. Falling snow will soon melt when the wet-bulb temperature becomes warmer than 0°C., and rain falling through a subfreezing layer will eventually freeze. Although surface temperature may be a good first-order approximation to forecast precipitation type, other factors must also be important since snow has occurred with surface temperatures greater than 4.4°C (40°F) and rain has occurred with surface temperatures less than -6.7°C (20°F). Of course, the snow melted when it struck the ground while the rain froze upon impact. Of additional importance in determining precipitation type is the variation of temperature with height in the lower few kilometers of the atmosphere.

One common meteorological parameter used in determining the mean temperature of an air column is the thickness or geopotential distance of a layer of air bounded by two pressure levels. The thickness is directly proportional to the mean virtual temperature of the air column. Since the mean virtual temperature is calculated from the dry-bulb temperature and a humidity characteristic (dew-point temperature, vapor pressure, mixing ratio, etc.) at a pressure level, the mean virtual temperature of a pressure stratum (as obtained from forecast thickness values) should be a useful tool in the prediction of precipitation type. This thesis will investigate the utility of thickness as an aid in forecasting precipitation types in Central Texas.

For a forecasting meteorologist, a knowledge of the values of different thicknesses that produce either snow, sleet, or mixed precipitation at a certain geographic location would be useful. Numerous studies in the past have shown that critical thickness values for frozen precipitation differ over geographical areas. Since frozen precipitation conditions are rare events in the Gulf States, conventional methods often fail to predict the correct precipitation in the south. Moreover, the rare frozen precipitation events in the southern states tend to be record-breakers when they do occur. Data bases have been established for southern cities, but the data base is often not adequate to produce dependable values.

This thesis will determine critical thickness values for Central Texas based on data obtained from five winter seasons at Waco, Austin, and San Antonio, Texas. The critical thickness values can be used in conjunction with other National Weather Service products such as the 850-1000 millibar (mb) thickness prognostic charts and the Limited-Area Fine Mesh (LFM-II) prognostic charts. The LFM product yields forecast values of 500-1000 mb thickness and (indirectly) also yields 700-1000 mb thickness for periods of 12, 24, 36, and 48 hours from the initial data inputs at 00Z and 12Z (midnight and noon Greenwich Mean Time) each day. Using the critical thickness values obtained in this study as guidelines, the forecaster can determine the conditional probabilities for precipitation types by inserting expected meteorological values into the output graphs obtained in this study.

The just-used term "conditional probability" refers to the probability that precipitation will be (or become) frozen once the probability of the occurrence of precipitation has been determined. Conditional probability is given by

$$P_{frozen} = (P_{frozen/precipitation}) \times (P_{precipitation}) ,$$

where P_{frozen} is the point probability that frozen precipitation will occur, $P_{frozen/precipitation}$ is the conditional probability that the frozen precipitation will occur given that precipitation does indeed occur, while $P_{precipitation}$ is the point probability that any precipitation will occur.

II. DATA COMPILATION & ANALYSIS

Data Used for this Study

A total of five winter seasons were used for this study:

(1) 1977-1978

(2) 1976-1977

(3) 1974-1975

(4) 1973-1974

(5) 1972-1973

The 1975-1976 season was omitted because of the unavailability of upper-level data and also because only two occurrences of frozen precipitation were observed during the entire winter period at the stations of interest. Although the 1975-1976 winter upper-level data could have been obtained from the National Climatic Center, it was decided that the five years used for this study had enough frozen precipitation cases to justify avoiding the time and expense required to include the very inactive 1975-1976 winter season in this study.

For the 1977-1978 winter season, 17 days were included for each of the three stations, Waco, Austin, and San Antonio, Texas. For the 1976-1977 season eleven days were studied, while there were seven days during the 1974-1975 season, six days during the 1973-1974 season, and eleven days during the 1972-1973 winter season. The total number of station days used was 156 days. In addition to examining the days on which some type of frozen phenomena occurred, the six hours preceeding and the six hours following each of the sequence of days were also included in this study.

The surface data required for this study were: (1) hourly surface temperature at each of the stations, (2) the hourly precipitation type at each of the stations, and (3) the hourly surface pressure at each of the stations. Although temperature and precipitation is available from teletype data (as is the upper-level data), surface pressure is not available from the hourly data. Surface pressures are transmitted on the Service C national teletype circuit at a frequency of once every six hours in the synoptic reports under the "SMUS" heading and coded as a group "6". However, since hourly surface pressures were needed, the only source of this data is the "WBANS-B", a standard form utilized at each of the three stations of interest. To facilitate matters, the entire series of "WBANS-A"s and "WBANS-B"s were obtained on microfiche for Waco, Austin, and San Antonio, Texas from the National Climatic Center for the five winter seasons used. It should be noted that the "WBANS-A"s contain the hourly surface temperature, the hourly precipitation type, precipitation intensity, and time of occurrence of each precipitation type, while the "WBANS-B"s contain the hourly surface pressure. A total of 66 data-months of microfiche data was obtained from the National Climatic Center. The periods of data used are tabulated in Table 1.

The Necessity for Uniform Data Sampling

During the data compilation process of this thesis, whenever either a "frozen" or a "freezing" precipitation type occurred between regular hourly observation times, it was noted. When the time came to

TABLE 1

PERIODS OF DATA USED

00Z 10 Dec 74 to 12Z 11 Dec 74	4 Synoptic Times*
00Z 25 Dec 74 to 12Z 26 Dec 74	4 Synoptic Times
00Z 11 Jan 75 to 12Z 13 Jan 75	6 Synoptic Times
00Z 6 Feb 75 to 12Z 7 Feb 75	4 Synoptic Times
00Z 22 Feb 75 to 12Z 24 Feb 75	6 Synoptic Times
00Z 12 Nov 76 to 12Z 15 Nov 76	8 Synoptic Times
00Z 28 Nov 76 to 12Z 29 Nov 76	4 Synoptic Times
00Z 31 Dec 76 to 12Z 3 Jan 77	8 Synoptic Times
00Z 8 Jan 77 to 12Z 10 Jan 77	6 Synoptic Times
00Z 30 Jan 77 to 12Z 31 Jan 77	4 Synoptic Times
00Z 1 Feb 77 to 12Z 2 Feb 77	4 Synoptic Times
00Z 2 Jan 74 to 12Z 4 Jan 74	6 Synoptic Times
00Z 29 Nov 77 to 12Z 30 Nov 77	4 Synoptic Times
00Z 1 Jan 78 to 12Z 3 Jan 78	6 Synoptic Times
00Z 9 Jan 74 to 12Z 13 Jan 74	10 Synoptic Times
00Z 11 Jan 78 to 12Z 13 Jan 78	6 Synoptic Times
00Z 18 Jan 78 to 12Z 20 Jan 78	6 Synoptic Times
00Z 21 Jan 78 to 12Z 23 Jan 78	6 Synoptic Times
00Z 31 Jan 78 to 12Z 1 Feb 78	4 Synoptic Times
00Z 7 Feb 78 to 12Z 10 Feb 78	8 Synoptic Times
00Z 15 Feb 78 to 12Z 18 Feb 78	8 Synoptic Times
00Z 3 Mar 78 to 12Z 5 Mar 78	6 Synoptic Times
00Z 19 Dec 73 to 12Z 20 Dec 73	4 Synoptic Times
00Z 21 Nov 72 to 12Z 22 Nov 72	4 Synoptic Times
00Z 10 Dec 72 to 12Z 13 Dec 72	8 Synoptic Times
00Z 8 Jan 73 to 12Z 12 Jan 73	10 Synoptic Times
00Z 8 Feb 73 to 12Z 10 Feb 73	6 Synoptic Times
00Z 17 Feb 73 to 12Z 18 Feb 73	4 Synoptic Times

*"Synoptic Times" occur every 12 hours at 00Z and 12Z (Greenwich Mean Time)

classify the precipitation types, several options presented themselves. If one precipitation type occurred during the observation time (the observation time at each station takes place 5 to 10 minutes before each clock hour), and another precipitation type occurred between the hourly observation times, then which classification type should be used ? Furthermore, if one precipitation type occurred at the observational hour and a different precipitation type started 15 minutes later, should this be included as a mixed-precipitation occurrence or a single precipitation occurrence, or both ? It was felt that using more than one precipitation classification per hour would ultimately bias the results of this study since a certain synoptic condition could be weighted too heavily in the overall sample set if more than one precipitation type were determined per hour. Therefore, only precipitation types observed during the regular hourly observation were included in the sample set. For example, if rain occurred at the observational time (5-10 minutes before the hour) and snow occurred 30 minutes later, the hour was classified as a "liquid" precipitation type, while the occurrence of snow, in this case, was ignored for the sake of a non-biased sample set.

Upper-Level Height Contour Analyses

Approximately 500 upper-level maps of the south central United States were plotted and analyzed. The regional analysis covered portions of the nation as far west as eastern Arizona and as far east as the Mississippi. The data covered the area as far south as Texas and Mexico and as far north as Kansas. The geostrophic approximation was used to complete the analysis in areas of sparce stations or missing data. Approximately 20 to 22 United States stations and 0 to 3 Mexican stations were used in the regional analysis. Often the transmission of upper-level data for the southwest U.S. and the non-U.S. stations was of a lower priority during the scheduled transmission of upper-level sounding data on the national teletype Service C, so most of the time the Mexican stations were missing.

The 500 mb contour map was analyzed for intervals of every 30 geopotential meters (gpm) on the regional map. After the regional analysis was completed, a more detailed analysis for the Central Texas area was performed using isopleths every 10 gpm.[1]

The 700 mb contour map was analyzed for every 10 gpm on a regional scale. After the regional analysis was completed, the Central Texas area was analyzed for a contour interval of each geopotential meter.

Similar to the 700 mb map, the 850 mb map was also analyzed for every 10 gpm on a regional scale, and was analyzed for every geopotential meter on a smaller (Central Texas) scale. The 850 mb analysis also had one more important data point in the vicinity of the Central Texas area, resulting from a low-level sounding taken in Houston. The Houston upper-level data was usually available only on weekdays and only at 12Z (6:00 A.M. CST). Supplementary soundings are made by the Houston station whenever the Texas Air Control Board in Austin, Texas requests

---

[1]It should be stated here that the National Weather Service reports 500 mb heights to the nearest 10 gpm during the data transmission over the national teletype Service C. Moreover, the 700 mb heights are reported to the nearest geopotential meter, while the 850 mb heights are also reported to the nearest geopotential meter.

the sounding during a severe air pollution episode; since this study took place during the winter months (during weather situations when low-level circulations were not stagnant), the data from Houston was mostly limited to only weekday mornings as regularly scheduled. Figure 1 shows one of the 500 maps analyzed for this study and used to obtain upper-level data for the Central Texas area.

Determination of Hourly Values for Upper-Level Data

Since frozen precipitation cases are rare in the Central Texas area, the difficulty in obtaining enough data to objectively calculate the conditional probability of frozen precipitation in Central Texas was anticipated. Using just the upper-level data and the associated surface data every twelve hours during a frozen precipitation case would be inadequate since the chances of obtaining a sufficient number of synoptic-time events[2] of frozen precipitation would be very rare. To increase the occurrence of these so called rare events, the eleven additional hours between the synoptic times were also used. By looking at every hour instead of every 12 hours, the amount of data in the data base was increased by a factor of 12. The problem with using data every twelve hours is that although most of the surface meteorological parameters are available every hour of the day, the upper-level data is only available every 12 hours.

The easiest analytical method of determining hourly values of upper-level height-contour data is to simply linearly interpolate the

[2]"synoptic-time events" are considered to be events that occur every 12 hours during the synoptic times of 00Z and 12Z (Greenwich Mean Time).

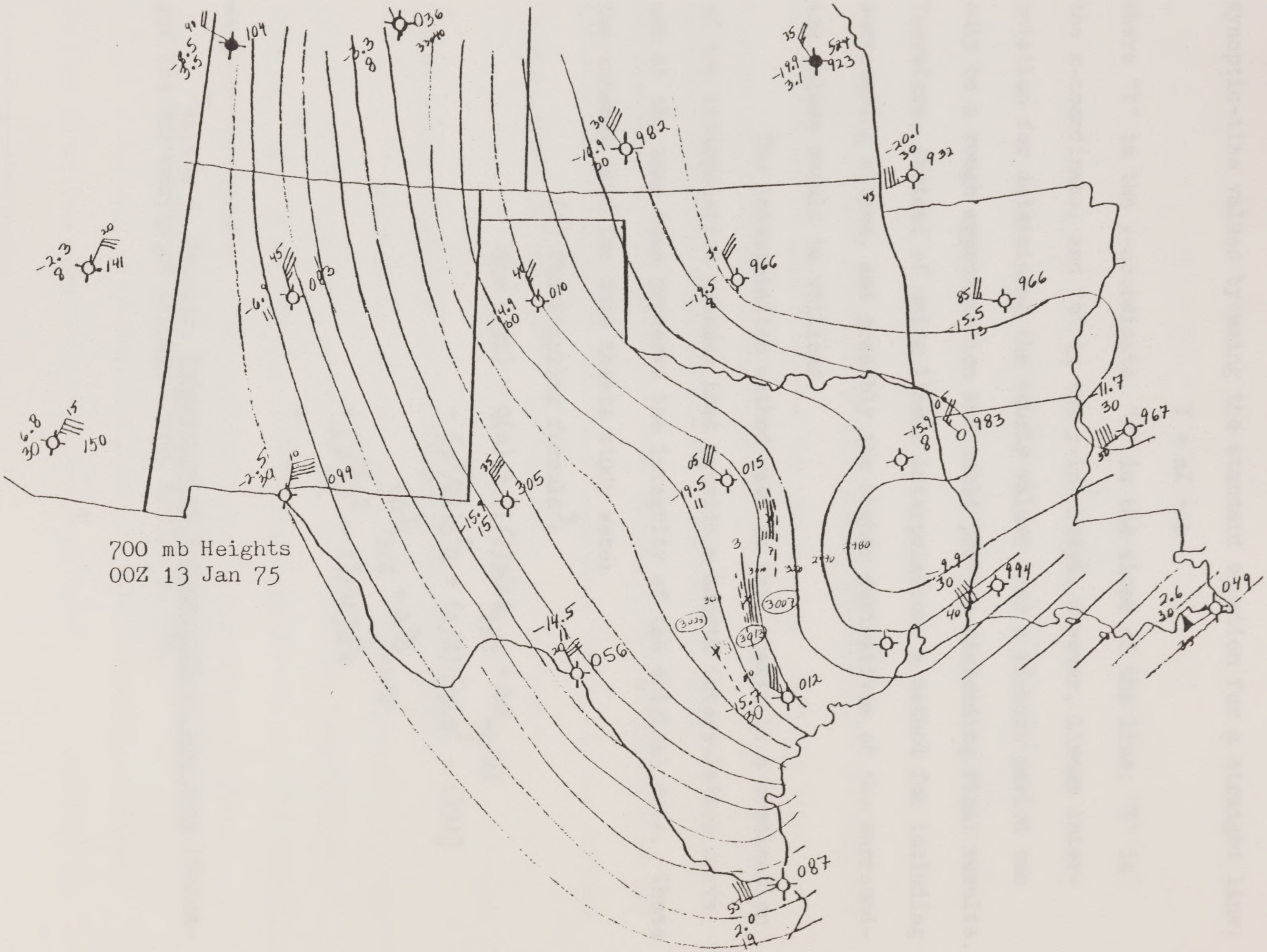


Figure 1. Example of an Upper-Level Regional Contour Analysis

synoptic-time values by using the standard equation for a straight line:

$$Y = mX + b$$

where "Y" is the y-coordinate, "m" is the slope of the line, "X" is the x-coordinate, and "b" is the y-intercept. However, linear interpolation for determining the hourly values over a 12-hour period can only be a rough approximation and could provide misleading final results. Therefore, instead of using linear interpolation, a method for including surrounding slopes, and possibly the higher derivatives of the surrounding values should be utilized.

The interpolation method used in this thesis is a combination of two interpolation schemes that provide a smooth interpolation curve and at the same time preserve the integrity of the original data. These two schemes used for this thesis study were:

(1) The Stirling formula[3]:

$$\begin{aligned} Q(s + pi) = Q(s) &+ (1/2)p(\Delta Q_{1/2} + \Delta Q_{-1/2}) \\ &+ (p^2/2!)\Delta^2 Q + (1/2)\,[p(p^2 - 1)3!] \\ &\quad (\Delta^3 Q_{1/2} + \Delta^3 Q_{-1/2}) \\ &+ [p^2(p^2 - 1)/4!]\Delta^4 Q \\ &+ \ldots; \end{aligned}$$

---

[3]Walter J. Saucier, Principles of Meteorological Analysis (Chicago: The University of Chicago Press, 1955), p. 121.

(2) The Bessel formula[4]:

$$\begin{aligned} Q(s + pi) = {} & (1/2)[Q(s) + Q(s + i)] \\ & + (p - 1/2)\Delta Q_{1/2} + (1/2)[p(p - 1)/2!] \\ & \quad (\Delta^2 Q + \Delta^2 Q_1) \\ & + [p(p-1)(p - 1/2)/3!]\ \Delta^3 Q_{1/2} \\ & + (1/2)[p(p^2 - 1)(p - 2)/4!](\Delta^4 Q + \Delta^4 Q_1) \\ & + \ldots . \end{aligned}$$

These two formulas use a set of data points and calculate the complete continuous set of points between the initial set. Both the Stirling formula and the Bessel formula use the initial values of the upper-level data plus the average gradient between the initial values as well as the variation of the gradient.[5] The variation of the variation of the gradient is symbolized by the fourth derivative terms. It was decided to use up through the fourth derivate terms and no higher.

Compatibility of Sample-Data Development with Past Studies

It would not be wise to spend time doing a forecasting study if the methods used to develop the sample data differ significantly from past studies of a similar kind. Great pains were taken to determine the maximum possible error that could result from the calculations used in this thesis.

The only significant deviation of sample-data development in this study (in comparison with past studies) is the determination

---

[4]Ibid.

[5]Ibid.

of the 1000 mb height above mean sea level. All other data used in this study (surface temperature, surface pressure, precipitation type, height of the 850 mb, 700 mb, and 500 mb surfaces) were subject to the same instrument and observational error as other forecast studies. Therefore, the error introduced in this study by the calculation of the 1000 mb pressure level needs to be evaluated. The 1000 mb pressure level was calculated from the hypsometric equation. The error introduced by the use of the hypsometric equation is discussed in the following section.

Error Analysis for the Hypsometric Equation

Given a function,

$$F = f(x_1, x_2, \ldots, x_k), \tag{1}$$

its final solution is based on knowing the values of $x_1, x_2, \ldots, x_k$. If it is not possible to acquire these values and only approximate values $a_1, a_2, \ldots, a_k$ are known, then the final solution of the function shown in Equation (1) will have an inherent error based on the individual errors introduced by using the values $a_1, a_2, \ldots, a_k$ rather than the true values. The individual errors can be denoted by $\epsilon_1 = a_1 - x_1$, $\epsilon_2 = a_2 - x_2$, ..., $\epsilon_k = a_k - x_k$, where each of these errors is assumed to be much smaller than the respective approximate values of $a_1, a_2, \ldots, a_k$. Equation (1) now becomes

$$F = f(x_1, x_2, \ldots, x_k) =$$

$$f(a_1 - \epsilon_1, a_2 - \epsilon_2, \ldots, a_k - \epsilon_k). \tag{2}$$

Expanding the right side of Equation (2), while neglecting the higher order terms, it can be shown that[6]

$$F = f(x_1, x_2, \ldots, x_k) = f(a_1, a_2, \ldots, a_k) -$$

$$\epsilon_1(\partial f/\partial x_1) - \epsilon_2(\partial f/\partial x_2) - \ldots - \epsilon_k(\partial f/\partial x_k). \qquad (3)$$

The total uncertainty of Equation (1) can be symbolized as follows

$$\delta(F) = f(a_1, a_2, \ldots, a_k) - f(x_1, x_2, \ldots, x_k). \qquad (4)$$

where $\delta(F)$ is the total uncertainty of the function.

Since the individual uncertainties of each term of the function are symbolized by $\epsilon_1, \epsilon_2, \ldots, \epsilon_k$, using the same symbolism as that used in Equation (4), Equation (3) can be simplified to the following[7]

$$\delta(F) = |(\partial f/\partial x_1)\delta x_1| + |(\partial f/\partial x_2)\delta x_2| + \ldots +$$

$$|(\partial f/\partial x_k)\delta x_k|. \qquad (5)$$

where $\delta(F)$ is the total uncertainty of the functional value of the equation; $(\partial f/\partial x_1)$, $(\partial f/\partial x_2)$, ..., $(\partial f/\partial x_k)$ are the partial derivatives of the function with respect to the $x_1, x_2, \ldots, x_k$ arguments; and $\delta x_1, \delta x_2, \ldots, \delta x_k$ are the respective uncertainties in each of the

---

[6] W. Gellert et al., eds., "Calculus of Errors," The VNR Concise Encyclopadia of Mathematics, 1st American ed. (New York: Van Nostrand Reinhold Co., 1977), p. 611.

[7] S.J. Kline and F.A. McClintock, "Describing Uncertainties in Single-Sample Experiments," Mechanical Engineering, January 1953, p. 6.

$x_1, x_2, \ldots, x_k$ arguments.

For the hypsometric equation,

$$\Delta Z = -(R_d/g)\bar{T}^* \ln(p_2/p_1), \qquad (6)$$

the arguments in Equation (6) that correspond to arguments in Equation (5) are as follow: "ΔZ" (the thickness) is F, "R_d" (the gas constant) is x_1, "g" (the acceleration due to gravity) is x_2, "$\bar{T}^*$" (the mean virtual temperature) is x_3, "p_2" (the pressure at the top of the layer) is x_4, and "p_1" (the pressure at the bottom of the layer) is x_5. Therefore, the uncertainty analysis equation as applies to the hypsometric equation can be given as

$$\delta(\Delta Z) = |(\partial f/\partial R_d)\delta R_d| + |(\partial f/\partial g)\delta g| + |(\partial f/\partial \bar{T}^*)\delta \bar{T}^*| + |(\partial f/\partial p_1)\delta p_1| + |(\partial f/\partial p_2)\delta p_2|. \qquad (7)$$

Since the partial derivative of a constant is zero, the first term on the right-hand side of Equation (7) equals zero since R_d is constant. The acceleration due to gravity, g, is a function of both latitude and height[8]; however, the National Weather Service assumes this term is constant.[9] Therefore, the second term on the right-hand side of Equation (7) also equals zero. What remains of Equation (7) is

---

[8] Robert J. List, ed., Smithsonian Meteorological Tables, 6th rev. ed. (Washington, D.C.: Smithsonian Institution Press, 1949), p. 490.

[9] U.S., Department of Commerce, Weather Bureau, Manual of Radiosonde Observations (WBAN) Circular P, 7th ed. (Washington, D.C.: U.S. Government Printing Office, June 1957; reprint ed. with changes, April 1963), pp. 256-67.

$$\delta(\Delta Z) = |(\partial f/\partial \bar{T}^*)\delta \bar{T}^*| + |(\partial f/\partial p_1)\delta p_1|. \quad (8)$$

Equation (8) can be interpreted as saying that the uncertainty in the value of the geopotential distance between p_2 and p_1, i.e., ΔZ, is a function of both: (1) $\delta\bar{T}^*$, the uncertainty in the value of the mean virtual temperature of the air column bounded by p_2 and p_1, and (2) δp_1, the uncertainty in the value of p_1.

To find the sensitivity of ΔZ_{1000} (geopotential height of the 1000 mb pressure level with respect to the surface pressure) in the hypsometric equation with respect to the mean virtual temperature, the first term on the right side of Equation (8) needs to be evaluated. This term will tell us the contribution to the total uncertainty in ΔZ_{1000} that results from an error in the mean virtual temperature, $\bar{T}^*$. The first term on the right side of Equation (8) is evaluated as follows:

$$|(\partial[\Delta Z_{1000}]/\partial \bar{T}^*)\delta\bar{T}^*| = |-(R_d/g)\ \ln(p_2/p_1)\delta\bar{T}^*|. \quad (9)$$

Using an R_d value of 2.8704×10^6 erg $g.^{-1}$ $^oK.^{-1}$, [10] a "g" value (for mean sea level and 45° latitude) of 9.80616 m. $sec.^{-2}$, [11] and a p_2 value of 1000 mbs, Equation (9) becomes

$$|(\partial[\Delta Z_{1000}]/\partial\bar{T}^*)\delta\bar{T}^*| = |-29.2714\ m.^oK^{-1}\ \ln(1000\ mbs/p_1)\delta\bar{T}^*|. \quad (10)$$

Numerical evaluation of Equation (10) yields the contribution of the uncertainty of $\bar{T}^*$ to the total uncertainty of the value of ΔZ_{1000}.

---

[10] List, Meteorological Tables, p. 289.

[11] Ibid., p. 4.

The value of this uncertainty is $(-150.545\ \text{cm.}/^{\circ}\text{K})\bar{T}^*$ for an assumed representative surface pressure of 949.9 mbs. Calculations using Equation (10), and the hypsometric equation give the results shown in Table 2.

TABLE 2

THE UNCERTAINTIES IN ΔZ_{1000} RESULTING FROM INDIVIDUAL UNCERTAINTIES IN $\bar{T}^*$
(Uncertainties expressed as percentages)

$\delta\bar{T}^*$	$(\delta\bar{T}^*/\Delta Z_{1000})$
$1\ ^{\circ}$K	0.37%
$2\ ^{\circ}$K	0.73%
$3\ ^{\circ}$K	1.10%

Table 2 shows that any errors introduced into the calculation of ΔZ_{1000} by using an approximated mean virtual temperature, $\bar{T}^*$, are very small. Using a sample value of 100 geopotential meters (gpm) as a realistic test value for ΔZ_{1000}, the error introduced by a 3°K error in estimating the mean virtual temperature in the air column bounded by surface pressure and the 1000 mb pressure level are of the order of only 1.10%, or approximately 1.1 gpm. Therefore, the ΔZ_{1000} value would be written as 100 gpm $\pm$ 1.1 gpm, assuming all other uncertainties have been eliminated.

For large ΔZ_{1000} values, i.e., $p_1 \ll 1000$ mbs, or $p_1 \gg 1000$ mbs, the percentage errors remain the same although the magnitude of the errors increase. So for a ΔZ_{1000} value of 300 gpm, a 1.10% error results in an error of 3.3 gpm in the value of ΔZ_{1000}. Further calculations show that for station pressures ranging from 967 mbs to 1033 mbs, the uncertainty error resulting from a one degree Kelvin error in the mean virtual temperature will always be less than one geopotential meter.

The above error analysis indicates that using the hypsometric equation to calculate heights of the 1000 mb pressure level will introduce no significant errors to the results obtained in this thesis. It should be noted that the upper-level heights calculated from the interpolation equations can also introduce a possible error since the interpolated values are only estimations of the actual true values. This error cannot be calculated since the true values of the upper-level heights are not known. Any other errors or uncertainties in the values resulting from this thesis would originate from either observational errors in the original data used or analytical errors in the upper-level height analyses performed for this thesis.

Calculation of the Height of the 1000 mb Pressure Level

National Weather Service procedures were used to calculate the height of the 1000 mb surface at a station whenever the 1000 mb surface was located below the station, i.e., whenever the surface pressure at the station was less than 1000 mb. The procedures, as listed in Circular P[12] are to obtain a station temperature argument (t^1) from the current station temperature and the station temperature 6 hours previously. The purpose of the station temperature argument is to minimize the short-time diurnal temperature effects at the station. Once

---

[12] U.S., Circular P, pp. 169-70.

the temperature argument has been calculated, it is utilized in Table 13 of Circular P.[13] Table 13 converts the temperature argument into the mean virtual temperature of the air column bounded by the surface pressure and the 1000 mb pressure height (in this case the air column is underground). The data correction factors that are used in Table 13 are very crude approximations based on climatological data from five U.S. stations. Once the mean virtual temperature of the air column has been calculated, it is used in Table 14 of Circular P[14] to determine the height of the 1000 mb level.

In the case that the National Weather Service records a surface pressure that is above 1000 mbs, regulations call for the use of the temperature-dewpoint sounding to obtain an estimation of the relative humidity in the section of the sounding bounded by the surface pressure on the bottom and the 1000 mb level on the top. Once the relative humidity of the layer has been estimated, nomograms on the SKEW-T, LOG P diagram are used to calculate the thickness of this lowest stratum of the atmosphere. The last step necessary to obtain the height of the 1000 mb level when the 1000 mb level occurs above the station is to add the thickness of the lowest stratum to the elevation of the station to obtain the height of the 1000 mb surface.

The above two procedures would have been followed in this thesis had the upper-level data for each of the three Central Texas stations been available. Unfortunately, Waco, Austin, and San Antonio

---

[13]Ibid., p. 255.

[14]Ibid., pp. 256-67.

are not upper-level stations. Therefore, a method had to be devised to calculate the 1000 mb height when the surface pressure was greater than 1000 mbs. The method used by the National Weather Service to calculate 1000 mb heights when the surface pressure was below 1000 mbs posed no problem since the temperature data and the surface pressure data were available on an hourly basis for each of the Central Texas stations.

The remainder of this section shows how the method used by the National Weather Service to calculate 1000 mb heights below station altitude was used in this thesis to also calculate the 1000 mb height when the surface pressure was above 1000 mb (a few modifications were necessary).

The equation for the temperature argument, t^1, is:

$$t^1 = (1/3)(2t_o + t_{-6})$$

where "t_o" is the current surface temperature (^oF), and "t_{-6}" is the surface temperature 6 hours ago (^oF). The Texas Instrument (TI) 58 Programmable Calculator with Solid State Software was used to compute the temperature argument.

As was shown in the error analysis section, the hypsometric equation is not very sensitive to errors of a few degrees in the mean virtual temperature. To follow standard National Weather Service procedures, the method used to convert the temperature argument into the mean virtual temperature of the layer bounded by the surface pressure and the 1000 mb height is to use Table 13 of Circular P. The data in this table is based on the "assumed lapse-rate which is equal to one-half the dry adiabatic and mean humidity data derived from five U.S. stations".[15] Although this correction factor is fairly crude, it was used so that the results of this thesis would be compatible with National Weather Service products. The correction factors used by the National Weather Service in Circular P were extrapolated for pressures greater than 1000 mbs. The following equation was used (in conjunction with a Skew-T, Log P diagram)[16]:

$$\bar{T}^* = T + (1/6)w,$$

where "$\bar{T}^*$" is the virtual temperature (°C), "T" is the temperature (°C), and "w" is the saturation mixing ratio line passing through the dew-point curve at the same pressure level. Using this equation and the Skew-T, Log P digram, values were obtained for pressure levels above 1000 mbs. It was assumed that the dew-point curve was very close to the temperature curve at the given pressure, since this would give the maximum possible correction. The results show that the mean virtual temperature correction for pressures as high as 1020 mbs and 15°C was only two degrees. Since most of the data used in this thesis consisted of temperatures between 25°F (-3.9°C) and 44°F (6.7°C) most of the corrections to the temperature were one degree Celsius or less.

Table 3 shows the values used in this thesis to convert the temperature argument into the mean virtual temperature between the

---

[15] Ibid., p. 255.

[16] U.S., Air Force, Air Weather Service, Use of the Skew T, Log P Diagram in Analysis and Forecasting, A.W.S. Manual 105-124 (Scott Air Force Base, Ill.: Headquarters Air Weather Service, 15 July 1969), p. 4.9 .

TABLE 3

CORRECTION FACTORS FOR THE STATION TEMPERATURE ARGUMENT

STATION PRESSURE (MBS/IN. Hg)	STATION TEMPERATURE ARGUMENT (^{o}C) -15	-10	-5	0	+5	+10	+15	+20	
1020/30.121	0	0	0	1	1	1	2	2	Calculated from Skew-T, Log P Diagram.
29.973									
1010/29.825	0	0	0	1	1	1	2	2	
29.678									
1000/29.530	0	0	0	0	1	1	1	2	from Table 13 of Circular P.
29.382									
990/29.235	0	0	0	1	1	1	2	2	
29.087									
980/28.939	0	1	1	1	1	1	2	2	
28.792									
970/28.644	1	1	1	1	1	2	2	2	

SOURCE: U.S. Department of Commerce. Weather Bureau. Manual of Radiosonde Observations (WBAN) Circular P. 7th ed. Washington, D.C.: U.S. Government Printing Office, June 1957; reprint ed. with changes, April 1963.

surface pressure and the 1000 mb pressure level. It should be emphasized that the values shown in Table 3 for pressures of 1000 mb or lower came directly from Circular P, while the values for pressures greater than 1000 mb were obtained from theoretical calculations. Circular P does not include values for those cases when the surface pressure is greater than 1000 mbs since the observed temperature-dewpoint curve can be used to evaluate the mean virtual temperature.

For this thesis no sounding data was available from any of the three Central Texas stations; hence, an extrapolated correction table, based on meteorological theory (and compatible with the corrections given in Circular P) had to be constructed (see Table 3).

The height of the 1000 mb pressure level was determined by the use of the hypsometric equation and the input of two variables: (1) another pressure level, and (2) the mean virtual temperature of the air layer bounded by the 1000 mb level and the other pressure level. The pressure level that was used as an input to the hypsometric equation was the actual station pressure at the station during the hour in question. Moreover, the mean virtual temperature was obtained from the hourly values of the temperature argument and the correction factor (as given in Table 3 of this thesis). Using these two inputs, the height of the 1000 mb pressure level was calculated on an hourly basis with the use of the Texas Instrument (TI) 58 Programmable Calculator.

The above 1000 mb heights were computed from the hypsometric equation, using an R_d/g value of 29.2692 m/^{o}K. This value of the "R_d/g" constant was the same value used by the National Weather Service to calculate height values in Table 14 of Circular P.[17]

---

[17] U.S., Circular P, pp. 256-67.

III. CLASSIFICATION METHODS USED

Classification of Precipitation for This Study

Fifteen different classifications of precipitation type were initially found in the thesis data base. These precipitation types were re-classified (grouped) from 15 different types into three major types (groups) for the sake of clarity. These three major re-classifications are: (1) "frozen" precipitation, (2) "freezing" precipitation, and (3) "liquid" precipitation. In the cases where both snow and rain occurred together (mixed) and also in the cases where both snow and freezing rain occurred together (also mixed), the "frozen" precipitation was chosen to represent these mixed precipitation types. It was felt that if the thermal parameters of the atmosphere were cold enough to produce snow, then the mixed precipitation occurrence should be re-classified as "frozen" regardless of the fact that "liquid" (rain) or "freezing" precipitation also occurred at the same time as the snow. Table 4 shows the original 15 classification types and the corresponding transformations into the three major precipitation types.

The Precipitation Classification System Used by the TDL

The classification system currently used by the Techniques Development Laboratory of the National Weather Service (TDL) entails the grouping of precipitation types into three major classifications: (1) "frozen", (2) "freezing", and (3) "liquid". A problem with this

TABLE 4

PRECIPITATION CLASSIFICATION SCHEME USED FOR THIS STUDY

PRECIPITATION TYPE	CLASSIFICATION	RE-CLASSIFICATION
1	Snow	Frozen
2	Snow Grains	Frozen
3	Ice Pellets	Frozen
4	Freezing Rain	Freezing
5	Rain	Liquid
6	Ice Pellets & Snow (Mixed)	Frozen
7	Freezing Rain & Snow (Mixed)	Frozen
8	Rain & Snow (Mixed)	Frozen
9	Freezing Rain & Ice Pellets (Mixed)	Frozen
10	Rain & Ice Pellets (Mixed)	Frozen
11	Freezing Rain & Ice Pellets & Snow (Mixed)	Frozen
12	Rain & Ice Pellets & Snow (Mixed)	Frozen
13	Snow Pellets	Frozen
14	Rain & Snow Pellets (Mixed)	Frozen
15	Freezing Rain & Snow Grains (Mixed)	Frozen

method of classification is that almost all of the mixed occurrences of frozen precipitation types are grouped in the "liquid" category. The only type of mixed precipitation type that is grouped into the frozen precipitation category is the mixed precipitation type of snow mixed with ice pellets. All other mixed precipitation types are grouped into the all liquid (rain) category, as detailed by the following:

> The PoPt system [Probability of Precipitation Type] gives conditional probability forecast for three precipitation type categories: frozen (snow or ice pellets), freezing (freezing rain or drizzle), and liquid (rain). Precipitation in the form of mixed snow and ice pellets is included in the frozen category; all other mixed precipitation types are included in the liquid category....[18]

An objection to the TDL classification system is that the occurrences of mixed precipitation types are suppressed into the large-sample "liquid" category. The occurrence of any type of frozen precipitation is relatively rare for the Central Texas area; therefore, its occurrence should not be subdued. If the thermal parameters of the atmosphere are cold enough to support frozen precipitation, it seems immaterial whether this precipitation is exclusively frozen, or whether this frozen precipitation occurs with unfrozen precipitation. The TDL probably employs the present system as a conservative measure to underpredict the occurrence of frozen precipitation types. This author believes that any mixed type of precipitation occurs under

---

[18] U.S., Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Operational Probability of Precipitation Type Forecasts Based on Model Output Statistics, by Joseph R. Bocchieri, Technical Procedures Bulletin No. 243 (Silver Spring, Maryland: Techniques Development Laboratory, August 10, 1978), p. 2.

atmospheric thermal conditions that are conducive to produce frozen precipitation. The classification system used in this thesis employs the fact that mixed precipitation types are the actual transition zone between liquid and frozen, and therefore, should be included in the rarer-occurring category, i.e., frozen.

The Importance of Including Rainfall Data in the Developmental Sample

In many of the cases studied in this thesis, the number of hours of rainfall, drizzle, rainshowers, thundershowers, etc. ("liquid" precipitation category) far outnumbered the cases of both the "frozen" (this "frozen" category included precipitation that is exclusively frozen or mixed) and the "freezing" precipitation categories. Actual results from this thesis indicate that out of 1416 hourly-precipitation occurrences, 933 of them were "liquid", 259 were "freezing", and 224 were "frozen". The hourly-precipitation occurrences of "liquid" precipitation were included in the developmental sample since it is important to catch all the borderline cases when the thermal parameters of the atmosphere were too warm to support a "frozen" or "freezing" precipitation occurrence. It is the purpose of this thesis to determine the thermal parameters necessary to produce non-liquid precipitation. Moreover, it is equally important to determine the thermal parameters necessary to reject a forecast of non-liquid precipitation. A large set of liquid-precipitation data, therefore, should intensify and support a meteorologist's decision not to include snow or freezing rain in his forecast, even though the surface temperature may be cold enough to suggest snow.

IV. SELECTION OF PRECIPITATION-TYPE PREDICTORS

The lower 50 mb (about 300 meters) of the atmosphere is probably the most important layer within which the stratification of thermal parameters will ultimately determine precipitation type. The National Weather Service measures heights of the mandatory levels (1000 mb, 850 mb, 700 mb, 500 mb,..., etc.) twice a day on the TTBB radiosonde group. Obviously the most suited mandatory level would be the 850 mb level (unfortunately the 950 mb level is not mandatory).

In 1964 C.J. Boyden claimed that the 500-1000 mb thickness "is a crude predictor because the form of precipitation is determined by the lowest levels of the atmosphere and at least nine-tenths of the layer up to 500 mb has little or no bearing on the problem."[19] The only reason that the 500-1000 mb thickness was used in early studies was that this thickness was a standard parameter utilized in synoptic analysis.[20] Boyden continues to narrow down the predictors as follows:

> It is obvious that the thickness of a shallower layer must be a more precise predictor. The 1000-700 mb layer, for example, excludes nearly half the irrelevant part included in the 1000-500 mb layer. It appears to be the less widely used of the two simply because the drawing of a 1000-700 mb thickness chart many not be justified by other commitments. [21]

It should be pointed out at this point that the 1000-700 mb thickness

---

[19]C.J. Boyden, "A Comparison of Snow Predictors," The Meteorological Magazine 93 (December 1964): 353.

[20]Ibid.

[21]Ibid.

is still not provided by the National Weather Service over the national Alfax or Nafax weather facsimile circuits. Boyden concluded that "The 1000-850 mb thickness is still better as a predictor of the form of precipitation because the melting layer extends through as much as one-quarter of its depth."[22] The melting layer can be considered to be the depth of the atmosphere between the 1000 mb level and the 950 mb level (assuming that the 1000 mb level is approximately at the surface and also assuming an above-freezing layer in these lowest 50 mb of the atmosphere).

Surface temperature should also be one of the joint predictors used in forecasting studies for the following two reasons:

(1) Surface temperature ultimately determines the precipitation type regardless of the upper-level temperature stratification, and

(2) There is a high correlation between surface temperature and upper-level thickness. This fact would justify using surface temperature in lieu of a second upper-level thickness since there would be no advantage to using a second upper-level thickness as the second of the two parameters in a joint predictor (the fact that surface temperature and upper-level thickness were highly correlated was shown in an unpublished report submitted by J.C. Ellis to the U.S. Weather Bureau in 1957).[23]

---

[22] Ibid., pp. 353-54.

[23] U.S., Department of Commerce, Weather Bureau, Forecasting Maximum and Minimum Temperatures, by Woodrow W. Dickey, Donald L. Jorgensen, ed., Forecasting Guide No. 4 (Washington, D.C.: Government Printing Office, March 1960), pp. 21-23.

V. GRAPHICAL RESULTS

Out of 1416 hours of precipitation data compiled, 224 were grouped into the "frozen" variety, 259 were grouped into the "freezing" variety, and 933 were grouped into the "liquid" variety. The following sections examine the data for both single and joint predictors. Figures 2 through 32 are the computer-generated graphical results obtained from the sorting out of the 1416 hours of precipitation data in the thesis sample data base.

Single Predictors: Conditional Probability Graphs and Categorical Decision Graphs

A computer program was used to sort out the sample data into graphs of conditional probabilities. These conditional probabilities were calculated by computing the relative frequencies of each category (frozen, freezing, and liquid) with respect to different values of thicknesses (850-1000 mb, 700-1000 mb, 500-1000 mb, 700-850 mb, 500-850 mb, and 500-700 mb) and with respect to different values of surface temperature. Figures 2 through 7 show these conditional probabilities for thicknesses, while Figure 8 shows the conditional probabilities for temperatures. Another computer program was written to select the category which predominated each of the thickness intervals as well as the category which predominated each of the temperature intervals. These categorical decision graphs appear on the lower right-hand corner of each of the respective figures.

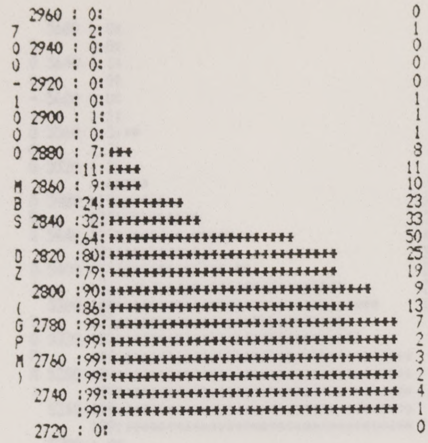
```
  1350 : 0:                                            0
8      : 0:                                            0
5 1340 : 0:                                            0
0      : 0:                                            0
- 1330 : 0:                                            0
1      : 1:                                            1
0 1320 : 0:                                            0
0      : 2:                                            2
0 1310 : 4:++                                          5
       : 6:+++                                         8
M 1300 : 5:++                                          6
B      :13:+++++                                      13
S 1290 :19:+++++++                                    14
       :34:++++++++++++                               25
D 1280 :52:+++++++++++++++++++                        39
Z      :52:+++++++++++++++++++                        33
  1270 :61:++++++++++++++++++++++                     32
(      :82:+++++++++++++++++++++++++++++              24
G 1260 :57:++++++++++++++++++++                        8
P      :83:++++++++++++++++++++++++++++++              5
M 1250 :99:+++++++++++++++++++++++++++++++++++         3
)      :99:+++++++++++++++++++++++++++++++++++         2
  1240 :99:+++++++++++++++++++++++++++++++++++         1
       :99:+++++++++++++++++++++++++++++++++++         3
  1230 : 0:                                            0

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN( 1 )
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.
```

```
  1350 :99:+++++++++++++++++++++++++++++++++++ 30
8      :99:+++++++++++++++++++++++++++++++++++ 29
5 1340 :99:+++++++++++++++++++++++++++++++++++ 44
0      :94:+++++++++++++++++++++++++++++++++   47
- 1330 :86:+++++++++++++++++++++++++++++++     50
1      :79:++++++++++++++++++++++++++++        54
0 1320 :85:++++++++++++++++++++++++++++++      83
0      :78:++++++++++++++++++++++++++++        78
0 1310 :76:+++++++++++++++++++++++++++         96
       :73:++++++++++++++++++++++++++          96
M 1300 :72:++++++++++++++++++++++++++          84
B      :51:++++++++++++++++++                  49
S 1290 :49:++++++++++++++++++                  35
       :35:+++++++++++++                       26
D 1280 :24:+++++++++                           18
Z      :15:++++++                              10
  1270 :21:++++++++                            11
(      :13:+++++                                4
G 1260 :35:+++++++++++++                        5
P      :16:++++++                               1
M 1250 : 0:                                     0
)      : 0:                                     0
  1240 : 0:                                     0
       : 0:                                     0
  1230 : 0:                                     0

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID( 5 )
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 83
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.
```

```
  1350 : 0:                                            0
8      : 0:                                            0
5 1340 : 0:                                            0
0      : 6:+++                                         3
- 1330 :13:+++++                                       8
1      :19:+++++++                                    13
0 1320 :14:+++++                                      14
0      :20:+++++++                                    20
0 1310 :19:+++++++                                    24
       :20:+++++++                                    26
M 1300 :22:++++++++                                   26
B      :34:++++++++++++                               33
S 1290 :30:+++++++++++                                22
       :30:+++++++++++                                22
D 1280 :22:++++++++                                   17
Z      :31:+++++++++++                                20
  1270 :17:++++++                                      9
(      : 3:++                                          1
G 1260 : 7:+++                                         1
P      : 0:                                            0
M 1250 : 0:                                            0
)      : 0:                                            0
  1240 : 0:                                            0
       : 0:                                            0
  1230 : 0:                                            0

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FREEZING( 4 )
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.
```

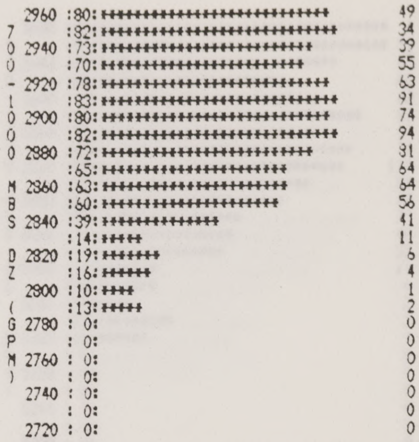
```
  1350 :R                  0   0  30
8      :R                  0   0  29
5 1340 :R                  0   0  44
0      :R                  0   3  47
- 1330 :R                  0   8  50
1      :R                  1  13  54
0 1320 :R                  0  14  83
0      :R                  2  20  78
0 1310 :R                  5  24  96
       :R                  8  26  96
M 1300 :R                  6  26  84
B      :R                 13  33  49
S 1290 :R                 14  22  35
       :R                 25  22  26
D 1280 :S                 39  17  18
Z      :S                 33  20  10
  1270 :S                 32   9  11
(      :S                 24   1   4
G 1260 :S                  8   1   5
P      :S                  5   0   1
M 1250 :S                  3   0   0
)      :S                  2   0   0
  1240 :S                  1   0   0
       :S                  3   0   0
  1230 :                   0   0   0

CATEGORICAL DECISION GRAPH
 ('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATION: ALL, PRECIPITATION TYPE: ALL
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 83
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON
LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES
FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.
```

Figure 2. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 850-1000 mb Thicknesses



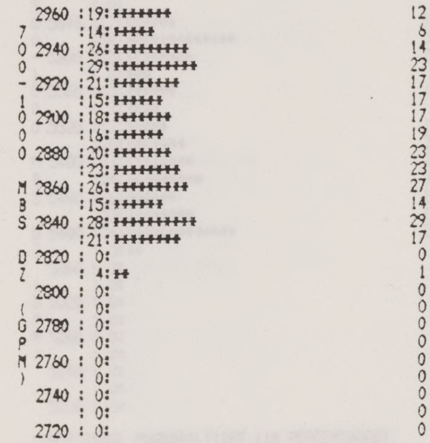
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN(1)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID(5)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 104
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CONDITIONAL PROBABILITIES (IN PERCENTAGES)

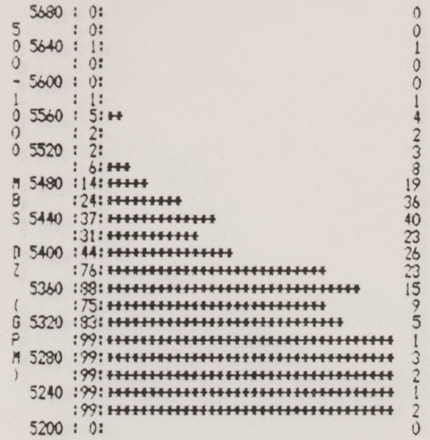
STATION: ALL, PRECIPITATION TYPE: FREEZING(4)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.

```
  2960 :R      0  12  49
7      :R      1   6  34
0 2940 :R      0  14  39
0      :R      0  23  55
- 2920 :R      0  17  63
1      :R      1  17  91
0 2900 :R      1  17  74
0      :R      1  19  94
0 2880 :R      8  23  81
       :R     11  23  64
M 2860 :R     10  27  64
B      :R     23  14  56
S 2840 :R     33  29  41
       :S     50  17  11
D 2820 :S     25   0   6
Z      :S     19   1   4
  2800 :S      9   0   1
(      :S     13   0   2
G 2780 :S      7   0   0
P      :S      2   0   0
M 2760 :S      3   0   0
)      :S      2   0   0
  2740 :S      4   0   0
       :S      1   0   0
  2720 :       0   0   0
```

CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

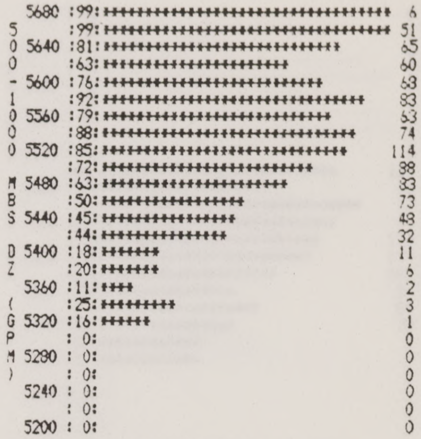
STATION: ALL, PRECIPITATION TYPE: ALL
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 104
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.

Figure 3. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 700-1000 mb Thicknesses



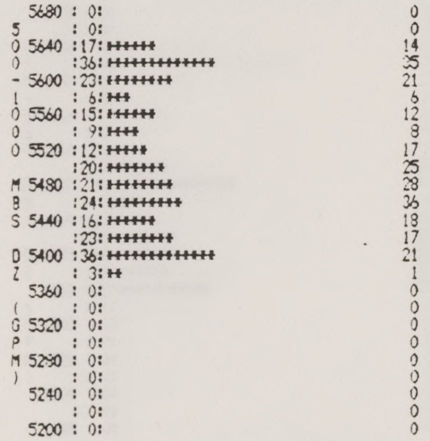
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN(1)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



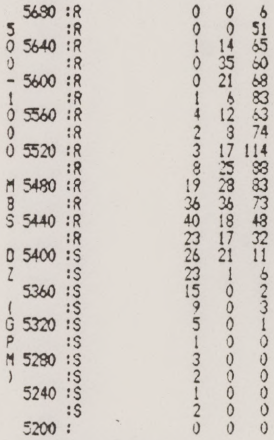
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID(5)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 2
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CONDITIONAL PROBABILITIES (IN PERCENTAGES)

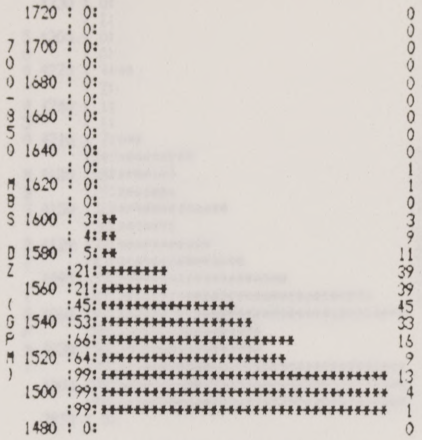
STATION: ALL, PRECIPITATION TYPE: FREEZING(4)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

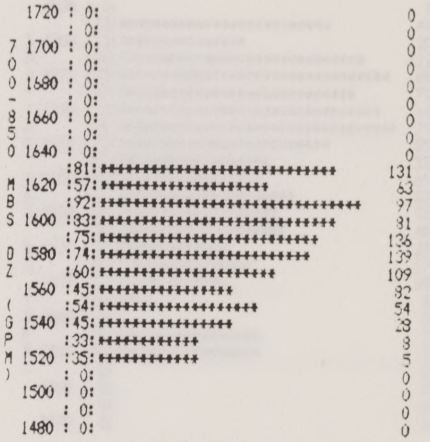
STATION: ALL, PRECIPITATION TYPE: ALL
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 2
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON
LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES
FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.

Figure 4. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 500-1000 mb Thicknesses



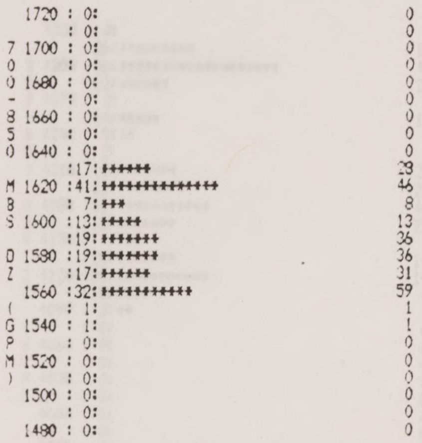
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN(1)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



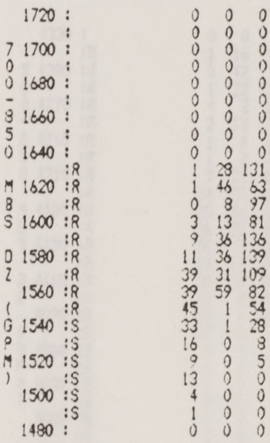
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID(5)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FREEZING(4)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATION: ALL, PRECIPITATION TYPE: ALL
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON
LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES
FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.

Figure 5. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 700-850 mb Thicknesses

```
  4330 : 0:                                      0
       : 1:                                      1
5 4300 : 0:                                      0
0      : 0:                                      1
0 4270 : 4:##                                    4
-      : 2:                                      2
8 4240 : 1:                                      1
5      : 1:                                      1
0 4210 : 7:###                                   9
       :24:#########                            24
M 4180 :18:#######                              25
B      :19:#######                              26
S 4150 :36:#############                        34
       :20:#######                              14
D 4120 :32:###########                          20
Z      :43:###############                      16
  4090 :59:####################                 16
(      :89:###############################      17
G 4060 :99:###################################   4
P      :50:#################                     2
M 4030 :50:#################                     1
)      :99:###################################   2
  4000 :99:###################################   2
       :99:###################################   2
  3970 : 0:                                      0

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN( 1 )
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.
```

```
  4330 : 0:                                      0
       :72:#########################            44
5 4300 :43:###############                      32
0      :84:#############################       121
0 4270 :93:################################     80
-      :83:#############################        77
8 4240 :92:################################     64
5      :96:#################################    79
0 4210 :73:#########################            85
       :52:##################                   52
M 4180 :50:#################                    69
B      :61:#####################                82
S 4150 :56:###################                  53
       :58:####################                 40
D 4120 :37:#############                        23
Z      :45:################                     17
  4090 :37:#############                        10
(      :10:####                                  2
G 4060 : 0:                                      0
P      :50:#################                     2
M 4030 :50:#################                     1
)      : 0:                                      0
  4000 : 0:                                      0
       : 0:                                      0
  3970 : 0:                                      0

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID( 5 )
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.
```

```
  4330 : 0:                                      0
       :26:#########                            16
5 4300 :56:####################                 42
0      :15:######                               22
0 4270 : 2:                                      2
-      :14:#####                                13
8 4240 : 5:##                                    4
5      : 2:                                      2
0 4210 :18:#######                              21
       :23:########                             23
M 4180 :31:###########                          44
B      :18:#######                              25
S 4150 : 7:###                                   7
       :20:#######                              14
D 4120 :30:###########                          19
Z      :10:####                                  4
  4090 : 3:##                                    1
(      : 0:                                      0
G 4060 : 0:                                      0
P      : 0:                                      0
M 4030 : 0:                                      0
)      : 0:                                      0
  4000 : 0:                                      0
       : 0:                                      0
  3970 : 0:                                      0

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FREEZING( 4 )
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.
```

```
  4330 :                0   0   0
       :R               1  16  44
5 4300 :#               0  42  32
0      :R               1  22 121
0 4270 :R               4   2  80
-      :R               2  13  77
8 4240 :R               1   4  64
5      :R               1   2  79
0 4210 :R               9  21  85
       :R              24  23  52
M 4180 :R              25  44  69
B      :R              26  25  82
S 4150 :R              34   7  53
       :R              14  14  40
D 4120 :R              20  19  23
Z      :R              16   4  17
  4090 :S              16   1  10
(      :S              17   0   2
G 4060 :S               4   0   0
P      :S               2   0   2
M 4030 :S               1   0   1
)      :S               2   0   0
  4000 :S               2   0   0
       :S               2   0   0
  3970 :                0   0   0

CATEGORICAL DECISION GRAPH
 ('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATION: ALL, PRECIPITATION TYPE: ALL
# OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON
LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES
FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.
```

Figure 6. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 500-850 mb Thicknesses

```
  2710 : 0:                                      0
       : 0:                                      0
5 2690 : 0:                                      0
0      : 2:                                      2
0 2670 : 4:##                                    5
-      : 0:                                      1
7 2650 : 0:                                      0
0      : 2:                                      3
0 2630 :25:#########                            25
       :17:######                               21
M 2610 :24:#########                            38
B      :20:#######                              24
S 2590 :25:#########                            24
       :33:###########                          22
D 2570 :38:#############                        15
Z      :30:###########                          15
  2550 :37:#############                        13
(      :77:##########################            7
G 2530 :80:###########################           4
P      :50:#################                     1
M 2510 : 0:                                      0
)      :99:#################################     1
  2490 :99:#################################     2
       :99:#################################     1
  2470 : 0:                                      0
```

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN(1)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.

```
  2710 : 0:                                      0
       : 0:                                      0
5 2690 :53:##################                   33
0      :57:###################                  40
0 2670 :80:###########################          89
-      :91:###############################     141
7 2650 :89:##############################       95
0      :93:###############################     114
0 2630 :63:#####################                62
       :52:##################                   62
M 2610 :58:####################                 90
B      :64:######################               75
S 2590 :52:##################                   50
       :44:###############                      29
D 2570 :33:###########                          13
Z      :36:############                         18
  2550 :54:##################                   19
(      : 0:                                      0
G 2530 :20:#######                               1
P      :50:#################                     1
M 2510 :99:#################################     1
)      : 0:                                      0
  2490 : 0:                                      0
       : 0:                                      0
  2470 : 0:                                      0
```

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID(5)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.

```
  2710 : 0:                                      0
       : 0:                                      0
5 2690 :46:################                     29
0      :39:#############                        27
0 2670 :15:######                               17
-      : 7:###                                  12
7 2650 :10:####                                 11
0      : 4:##                                    5
0 2630 :11:####                                 11
       :29:##########                           35
M 2610 :17:######                               27
B      :14:#####                                17
S 2590 :22:########                             22
       :21:########                             14
D 2570 :28:##########                           11
Z      :32:###########                          16
  2550 : 8:###                                   3
(      :22:########                              2
G 2530 : 0:                                      0
P      : 0:                                      0
M 2510 : 0:                                      0
)      : 0:                                      0
  2490 : 0:                                      0
       : 0:                                      0
  2470 : 0:                                      0
```

CONDITIONAL PROBABILITIES (IN PERCENTAGES)

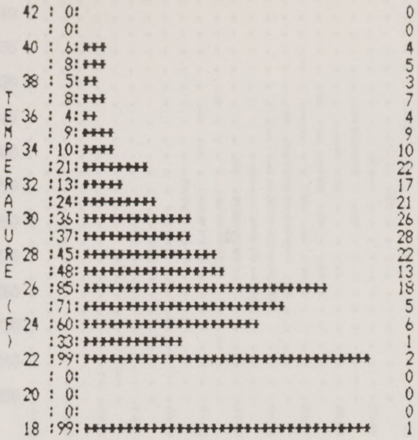
STATION: ALL, PRECIPITATION TYPE: FREEZING(4)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN
ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.

```
  2710 :              0   0   0
       :              0   0   0
5 2690 :R             0  29  33
0      :R             2  27  40
0 2670 :R             5  17  89
-      :R             1  12 141
7 2650 :R             0  11  95
0      :R             3   5 114
0 2630 :R            25  11  62
       :R            21  35  62
M 2610 :R            38  27  90
B      :R            24  17  75
S 2590 :R            24  22  50
       :R            22  14  29
D 2570 :S            15  11  13
Z      :R            15  16  18
  2550 :R            13   3  19
(      :S             7   2   0
G 2530 :S             4   0   1
P      :S             1   0   1
M 2510 :R             0   0   1
)      :S             1   0   0
  2490 :S             2   0   0
       :S             1   0   0
  2470 :              0   0   0
```

CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

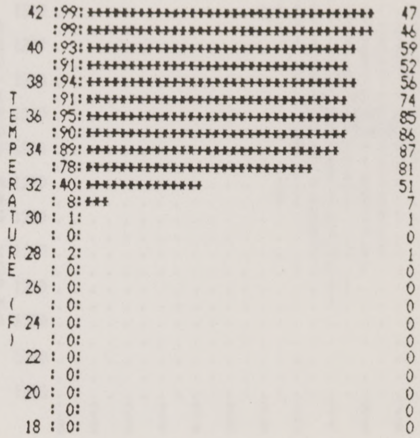
STATION: ALL, PRECIPITATION TYPE: ALL
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON
LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES
FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.

Figure 7. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for 500-700 mb Thicknesses



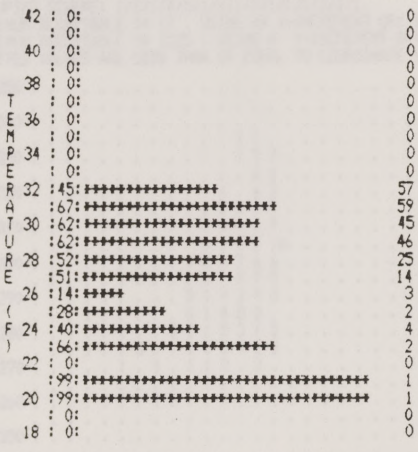
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: FROZEN(1)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 224
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 17 , USING A Y-INCREMENT OF: 1
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



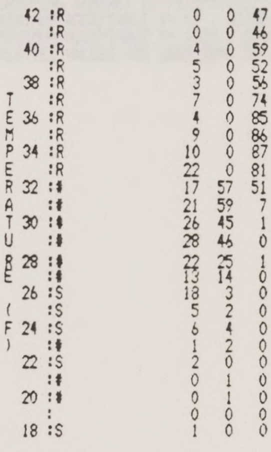
CONDITIONAL PROBABILITIES (IN PERCENTAGES)

STATION: ALL, PRECIPITATION TYPE: LIQUID(5)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 200
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 933
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 17 , USING A Y-INCREMENT OF: 1
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CONDITIONAL PROBABILITIES (IN PERCENTAGES)

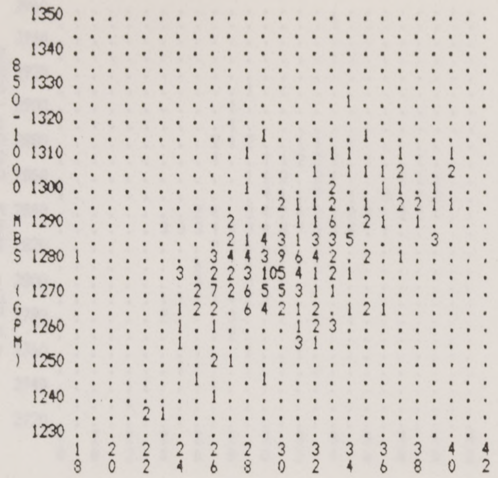
STATION: ALL, PRECIPITATION TYPE: FREEZING(4)
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 259
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 17 , USING A Y-INCREMENT OF: 1
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE RIGHT COLUMN DEPICTS SAMPLE FREQUENCIES.



CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATION: ALL, PRECIPITATION TYPE: ALL
OF HOURS NOT WITHIN ARRAY BOUNDARIES= 200
TOTAL HOURS SEARCHED= 1416 & TOTAL FOUND= 1416
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE Y= 17 , USING A Y-INCREMENT OF: 1
PLOTTED VALUES ARE LESS THAN OR EQUAL TO VALUES SHOWN ON LABELS. THE 3 RIGHT COLUMNS DEPICT SAMPLE FREQUENCIES FOR FROZEN, FREEZING, AND LIQUID CASES, RESPECTIVELY.

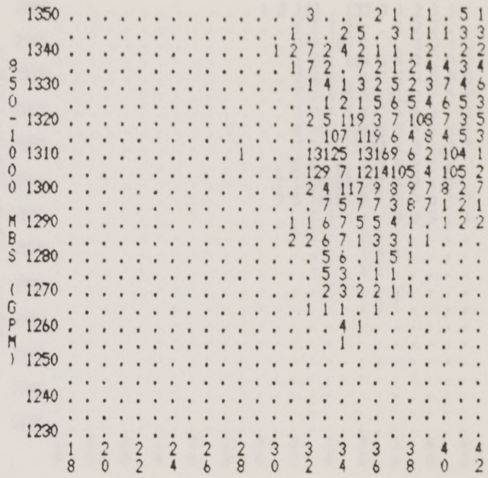
Figure 8. Single-Predictor Graphs for Conditional Probabilities & Categorical Decisions for Surface Temperatures



TEMPERATURE (F)

SAMPLE FREQUENCIES

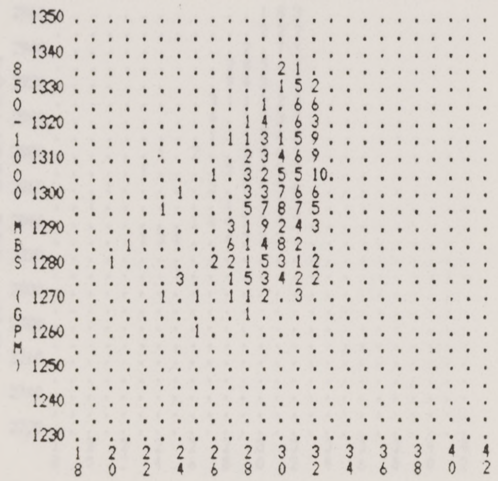
STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



TEMPERATURE (F)

SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 210
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

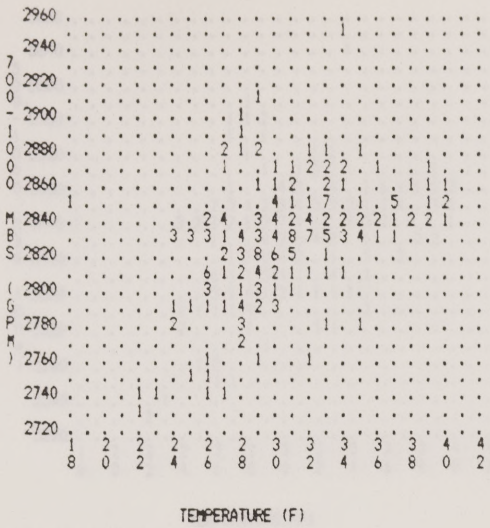


TEMPERATURE (F)

SAMPLE FREQUENCIES

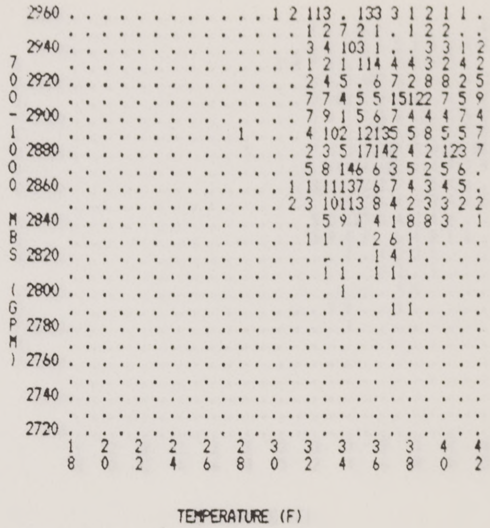
STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 9. Joint-Predictor Graphs of 850-1000 mb Thickness versus Surface Temperature



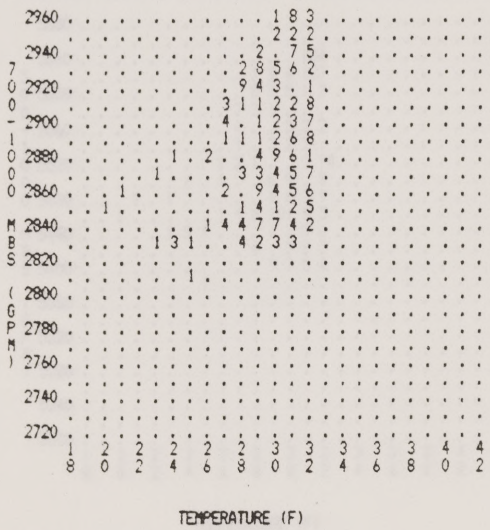
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

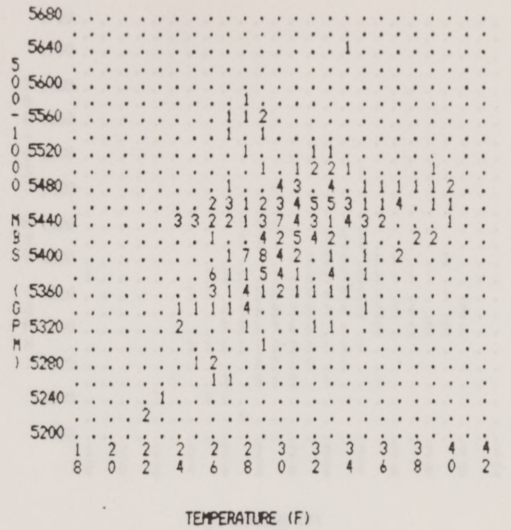
STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 234
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

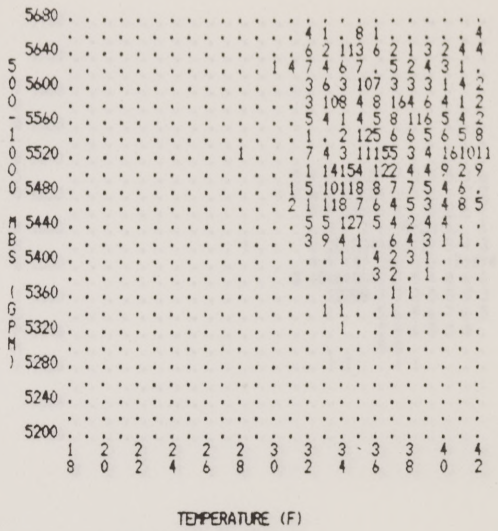
STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 10. Joint-Predictor Graphs of 700-1000 mb Thickness versus Surface Temperature



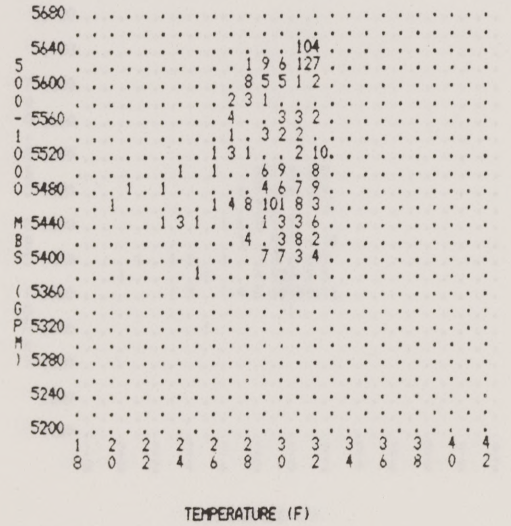
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 200
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



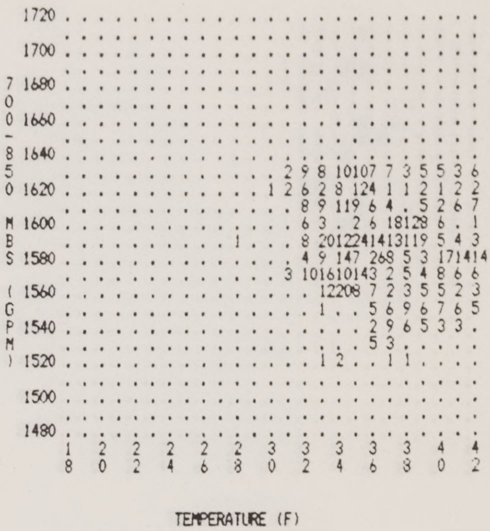
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 11. Joint-Predictor Graphs of 500-1000 mb Thickness versus Surface Temperature

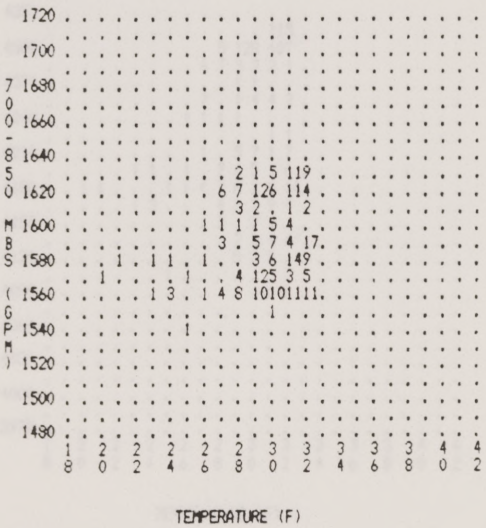
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

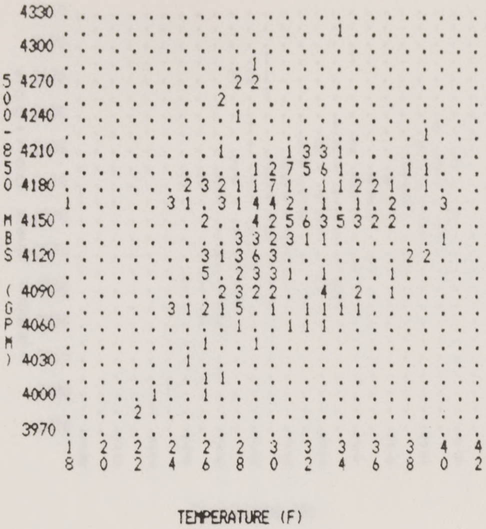
STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 200
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

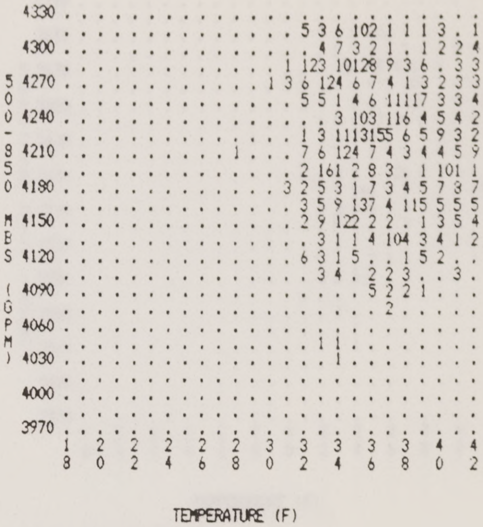
STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 12. Joint-Predictor Graphs of 700-850 mb Thickness versus Surface Temperature



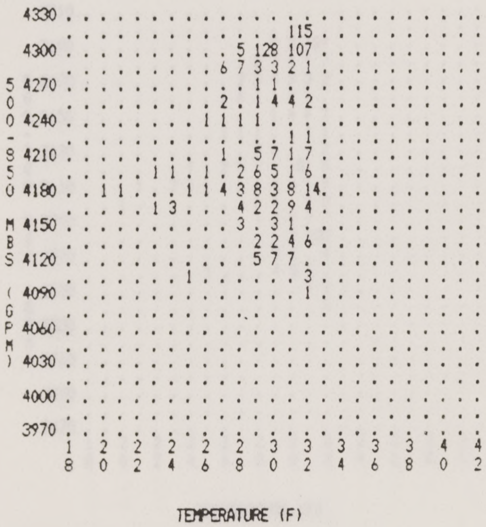
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

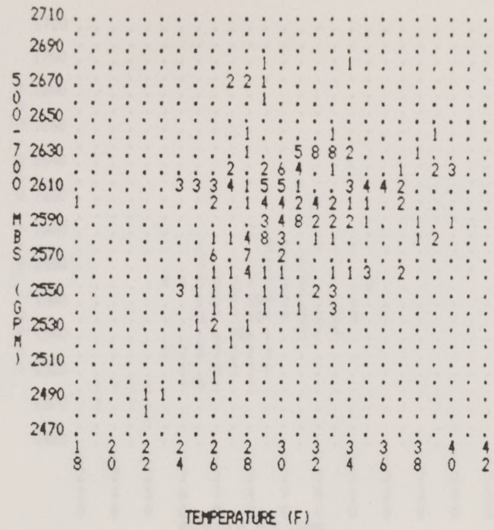
STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 200
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

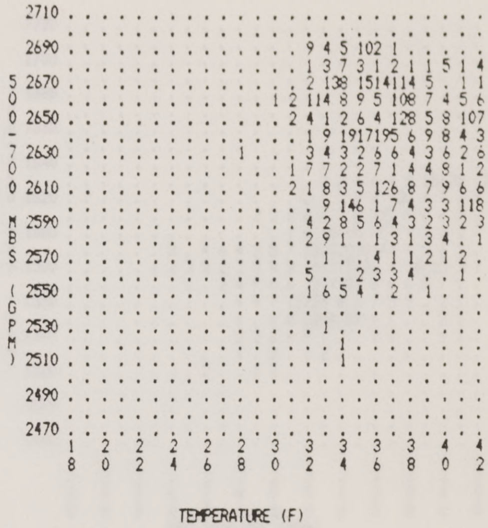
STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 13. Joint-Predictor Graphs of 500-850 mb Thickness versus Surface Temperature



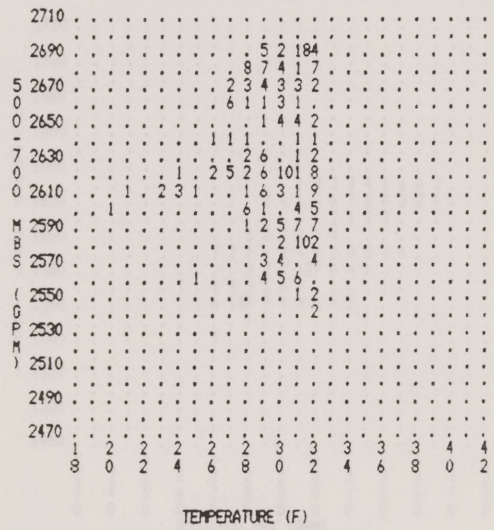
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

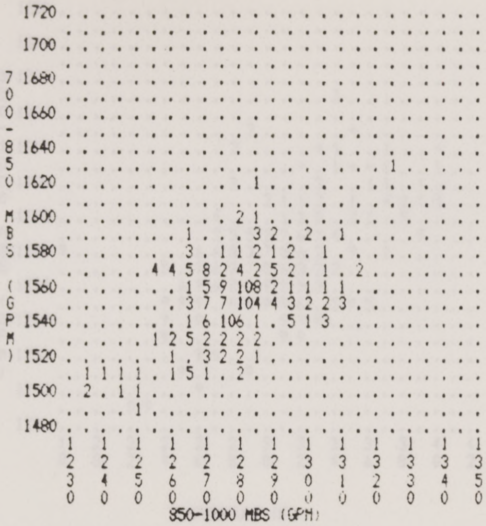
STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 200
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

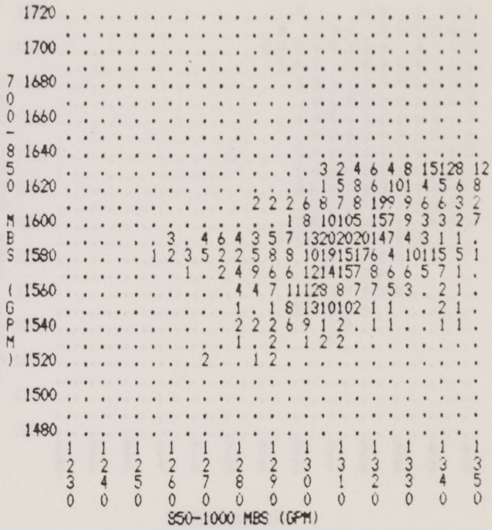
STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 14. Joint-Predictor Graphs of 500-700 mb Thickness versus Surface Temperature



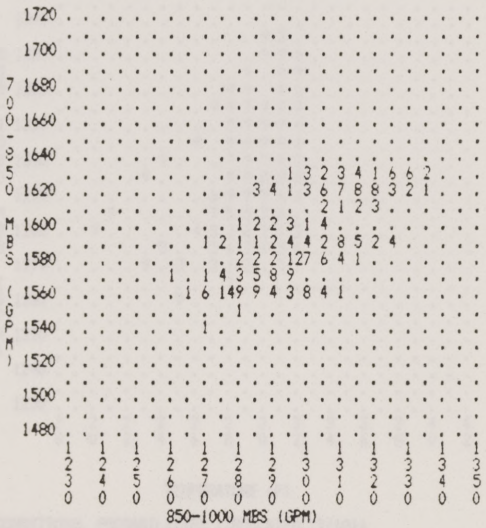
SAMPLE FREQUENCIES

STATIONS: ALL / PRECIPITATION TYPE: FROZEN
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 224 PT: 1
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

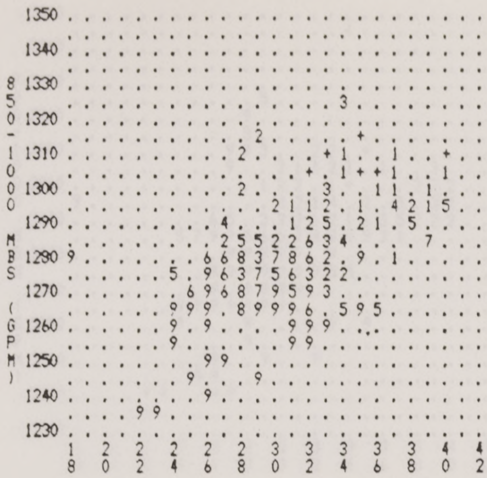
STATIONS: ALL / PRECIPITATION TYPE: LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 83
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 933 PT: 5
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

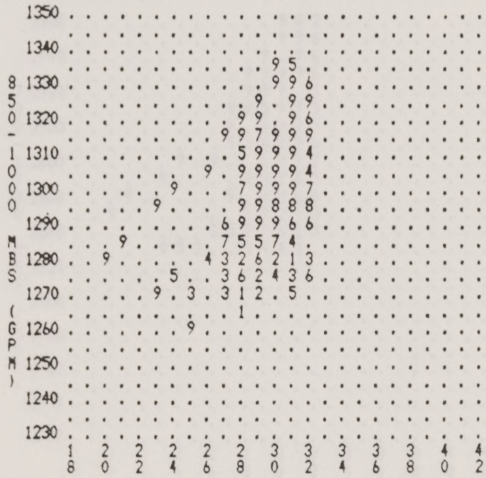
STATIONS: ALL / PRECIPITATION TYPE: FREEZING
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 259 PT: 4
GROUPING SCHEME: 1/1/1/4/5/1/1/1/1/1/1/1/1/1/1
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 15. Joint-Predictor Graphs of 700-850 mb Thickness versus 850-1000 mb Thickness



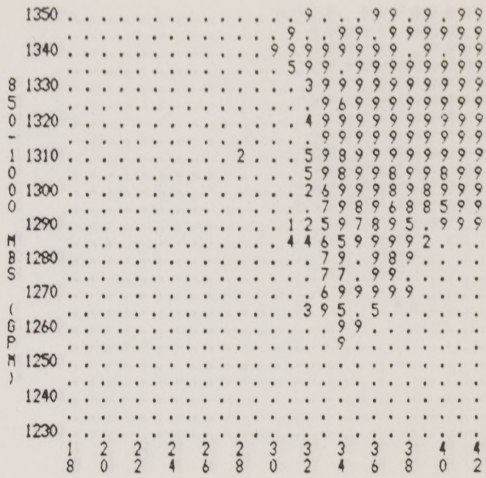
CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

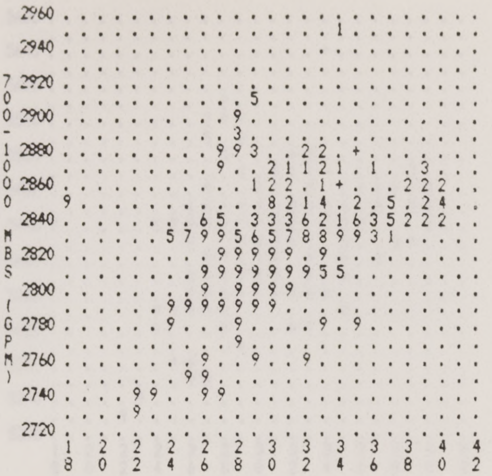
STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 259 PT: 4
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 210
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

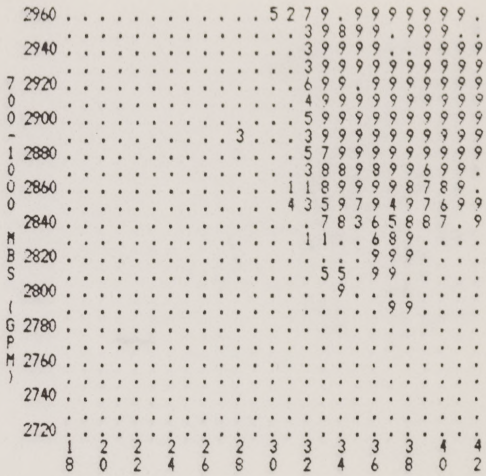
Figure 16. Joint-Predictor Graphs for Conditional Probabilities for 850-1000 mb Thickness versus Surface Temperature



TEMPERATURE (F)

CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

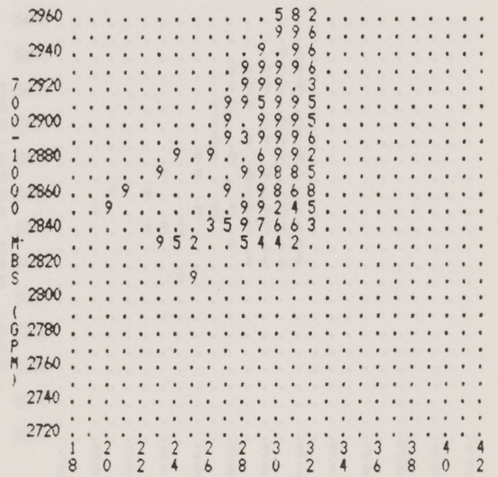
STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



TEMPERATURE (F)

CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 234
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

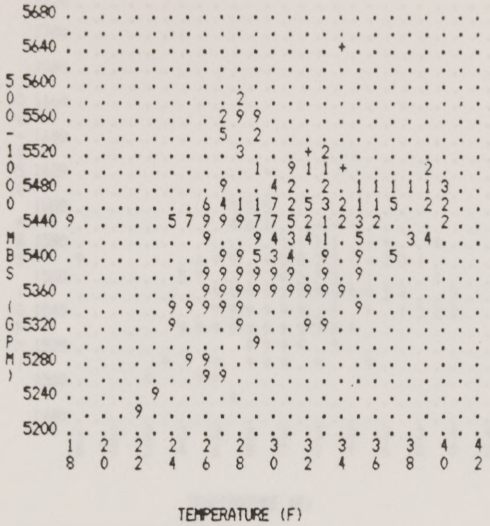


TEMPERATURE (F)

CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

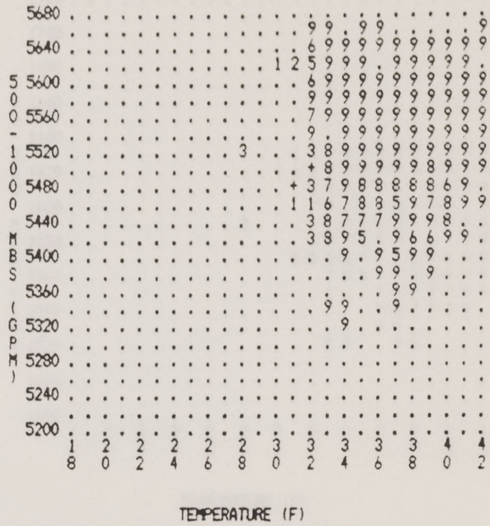
STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 4
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 17. Joint-Predictor Graphs for Conditional Probabilities for 700-1000 mb Thickness versus Surface Temperature



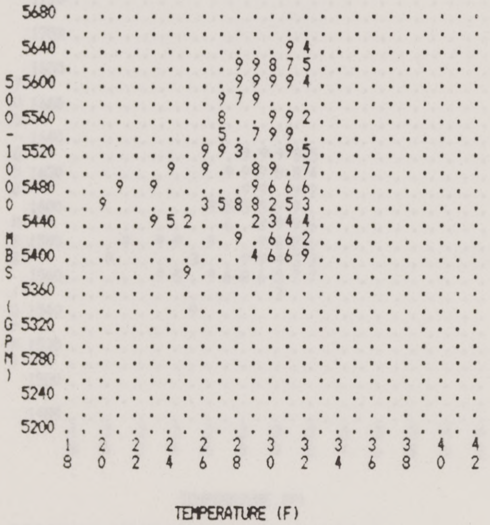
CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

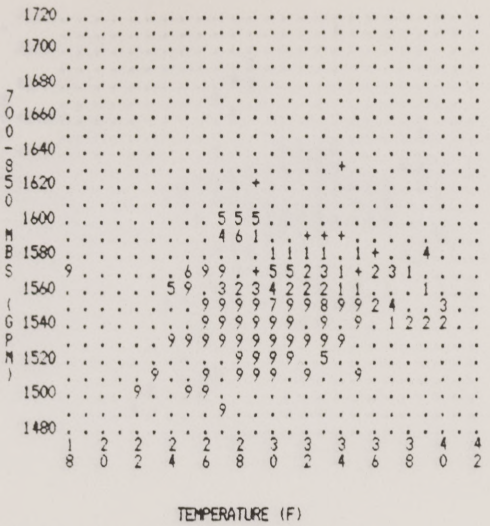
STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

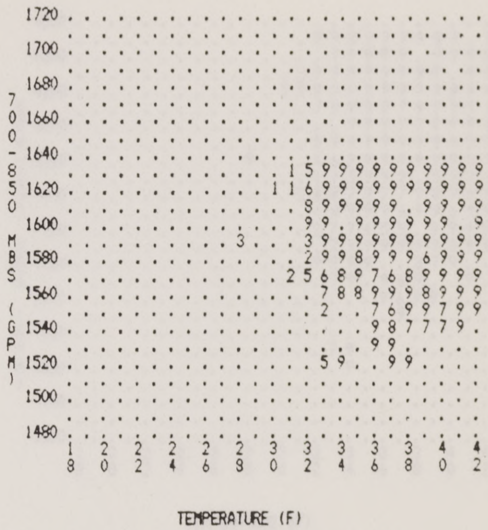
STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 259 PT: 4
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 18. Joint-Predictor Graphs for Conditional Probabilities for 500-1000 mb Thickness versus Surface Temperature



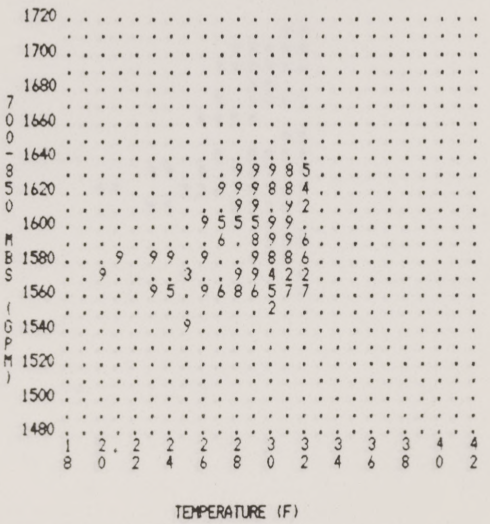
CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

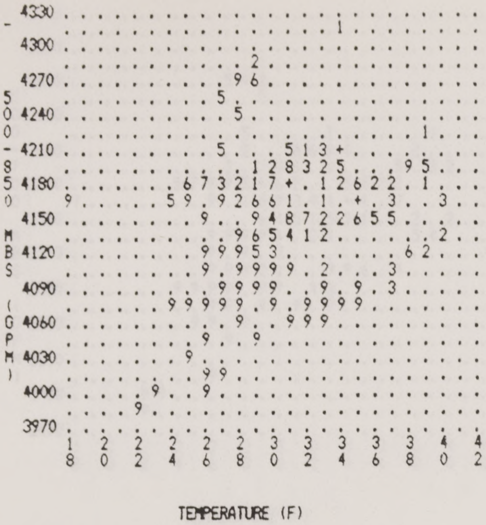
STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

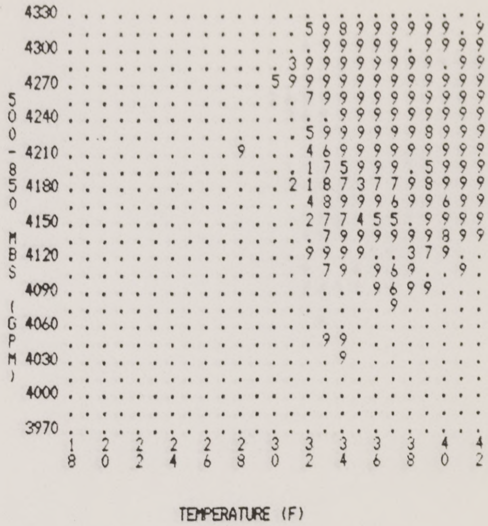
STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 259 PT: 4
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 19. Joint-Predictor Graphs for Conditional Probabilities for 700-850 mb Thickness versus Surface Temperature



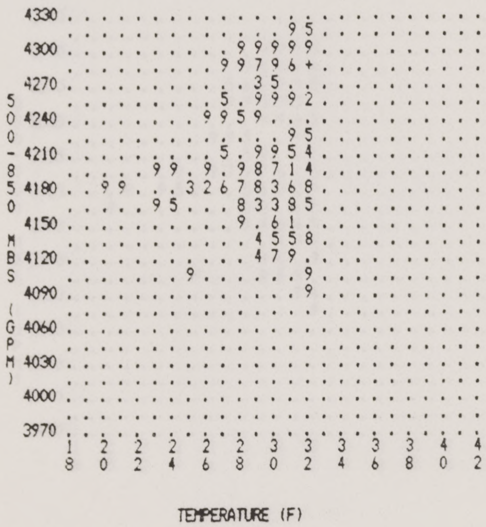
CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

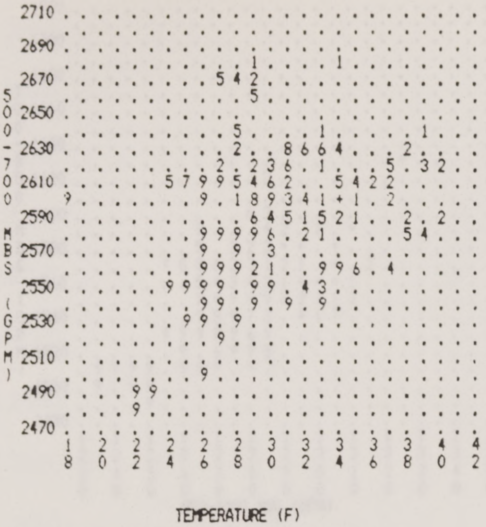
STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

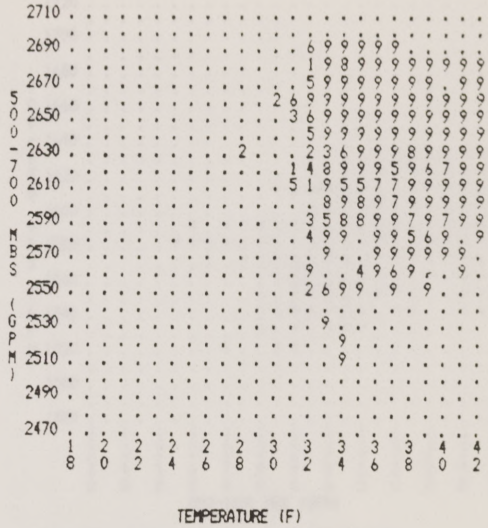
STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 259 PT: 4
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 20. Joint-Predictor Graphs for Conditional Probabilities for 500-850 mb Thickness versus Surface Temperature



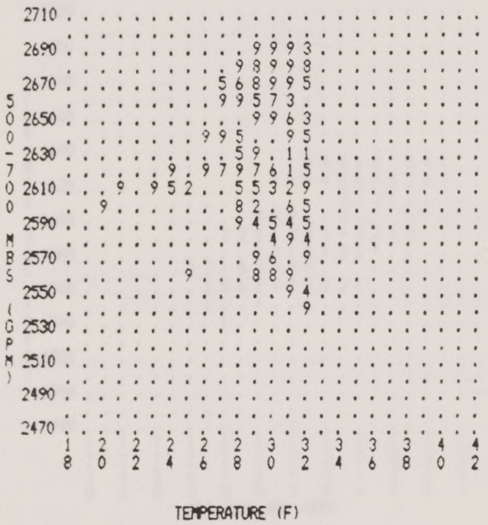
CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

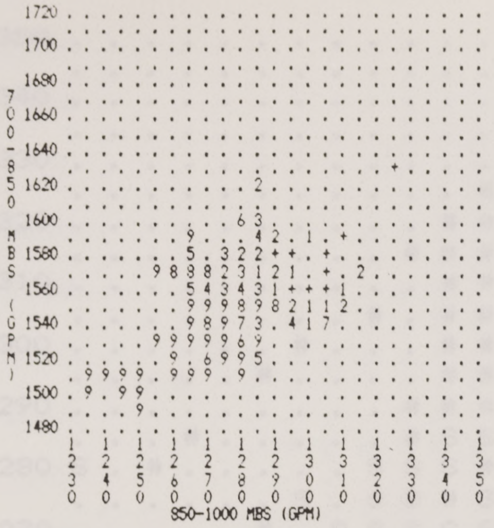
STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

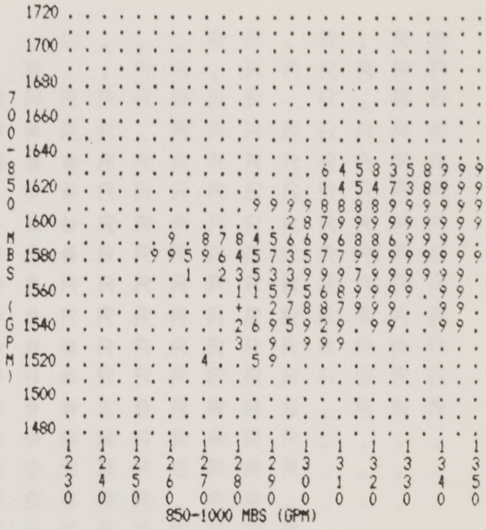
STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 259 PT: 4
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 21. Joint-Predictor Graphs for Conditional Probabilities for 500-700 mb Thickness versus Surface Temperature



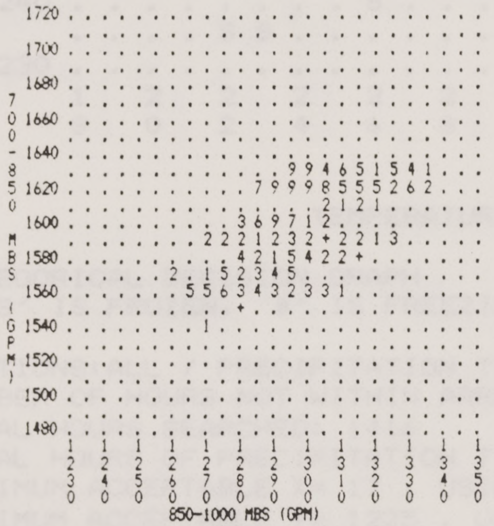
CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 1
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 224 PT: 1
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 5
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 83
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 933 PT: 5
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



CONDITIONAL PROBABILITIES (TRUNCATED (%/10))

STATIONS:ALL / PRECIPITATION TYPE: 4
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 0
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 259 PT: 4
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 22. Joint-Predictor Graphs for Conditional Probabilities for 700-850 mb Thickness versus 850-1000 mb Thickness

```
  1350 . . . . . . . . . . . . . . R . . . R R . R . R R
       . . . . . . . . . . . . . R . . R R . R R R R R R
  1340 . . . . . . . . . . . . R R R R R R R R . R . R R
       . . . . . . . . . . . . # # R R . R R R R R R R R
8 1330 . . . . . . . . . . . . # # # R R R R R R R R R R
5      . . . . . . . . . . . # . # # R R R R R R R R R R
0 1320 . . . . . . . . . . # # . # # R R R R R R R R R R
-      . . . . . . . . . # # # # # # R R R R R R R R R R
1 1310 . . . . . . . . . . # # # # R R R R R R R R R R R
0      . . . . . . . . # . # # # # R R R R R R R R R R R
0 1300 . . . . . . # . . . # # # # # R R R R R R R R R R
0      . . . . . # . . . . # # # # # R R R R R R R S R R
  1290 . . . . . . . . . # # # # # # S R R R R S . R R R
M      . . . # . . . . . # S S # # S R R R R R R S . . .
B 1280 S . # . . . . . S S S # S S S R R S R R R . . . .
S      . . . . . . S . S S # S S S # R R . R R . . . . .
  1270 . . . . . # . S S S S S S S S R R R R R R . . . .
(      . . . . . . S S S . S S S S S R S S S . . . . . .
G 1260 . . . . . . S # S . . . . S S S R R . . . . . . .
P      . . . . . . S . . . . . . S S . R . . . . . . . .
M 1250 . . . . . . . . S S . . . . . . . . . . . . . . .
)      . . . . . . . S . . . S . . . . . . . . . . . . .
  1240 . . . . . . . . S . . . . . . . . . . . . . . . .
       . . . . S S . . . . . . . . . . . . . . . . . . .
  1230 . . . . . . . . . . . . . . . . . . . . . . . . .
       1   2   2   2   2   2   3   3   3   3   3   4   4
       8   0   2   4   6   8   0   2   4   6   8   0   2

                    TEMPERATURE (F)
```

CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 210
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416 PT:ALL
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 23. Joint-Predictor Graph for Categorical Decisions for 850-1000 mb Thickness versus Surface Temperature

```
  2960 . . . . . . . . . . . . # # R R . R R R R R R R .
       . . . . . . . . . . . . # # # R R R R . R R R . .
  2940 . . . . . . . . . . . # . # # R R R R . . R R R R
       . . . . . . . . . . # # # # # R R R R R R R R R R
7 2920 . . . . . . . . . . # # # . R R R . R R R R R R R
O      . . . . . . . . . # # S # # # R R R R R R R R R R
O 2900 . . . . . . . . . # S # # # # R R R R R R R R R R
-      . . . . . . . . . # S # # # # R R R R R R R R R R
1 2880 . . . . . . # . # S S # # # R R R R R R R R R R R
O      . . . . . # . . . S # # # # # R R R R R R R R R .
O 2860 . . . # . . . . . # . # # # # R R R R R R R R R .
O      S . # . . . . . . . # # S # # R R R R S R R R R R
  2840 . . . . . . . . S S # # # # S R R S R S R R R . R
M      . . . . . # S S S S S S S S S S S S R R R . . . .
B 2820 . . . . . . . . . S S S S S . S . . R R R . . . .
S      . . . . . . . # S S S S S S S S S . R R . . . . .
  2800 . . . . . . . . S . S S S S . . R . . . . . . . .
(      . . . . . . S S S S S S S . . . . . . R R . . . .
G 2780 . . . . . . S . . . S . . . . S . S . . . . . . .
P      . . . . . . . . . . S . . . . . . . . . . . . . .
M 2760 . . . . . . . . S . . S . . S . . . . . . . . . .
)      . . . . . . . S S . . . . . . . . . . . . . . . .
  2740 . . . . S S . . S S . . . . . . . . . . . . . . .
       . . . . S . . . . . . . . . . . . . . . . . . . .
  2720 . . . . . . . . . . . . . . . . . . . . . . . . .
       1   2   2   2   2   2   3   3   3   3   3   4   4
       8   0   2   4   6   8   0   2   4   6   8   0   2

                      TEMPERATURE (F)

CATEGORICAL DECISION GRAPH
 ('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 234
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416  PT:ALL
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A  Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.
```

Figure 24. Joint-Predictor Graph for Categorical Decisions for

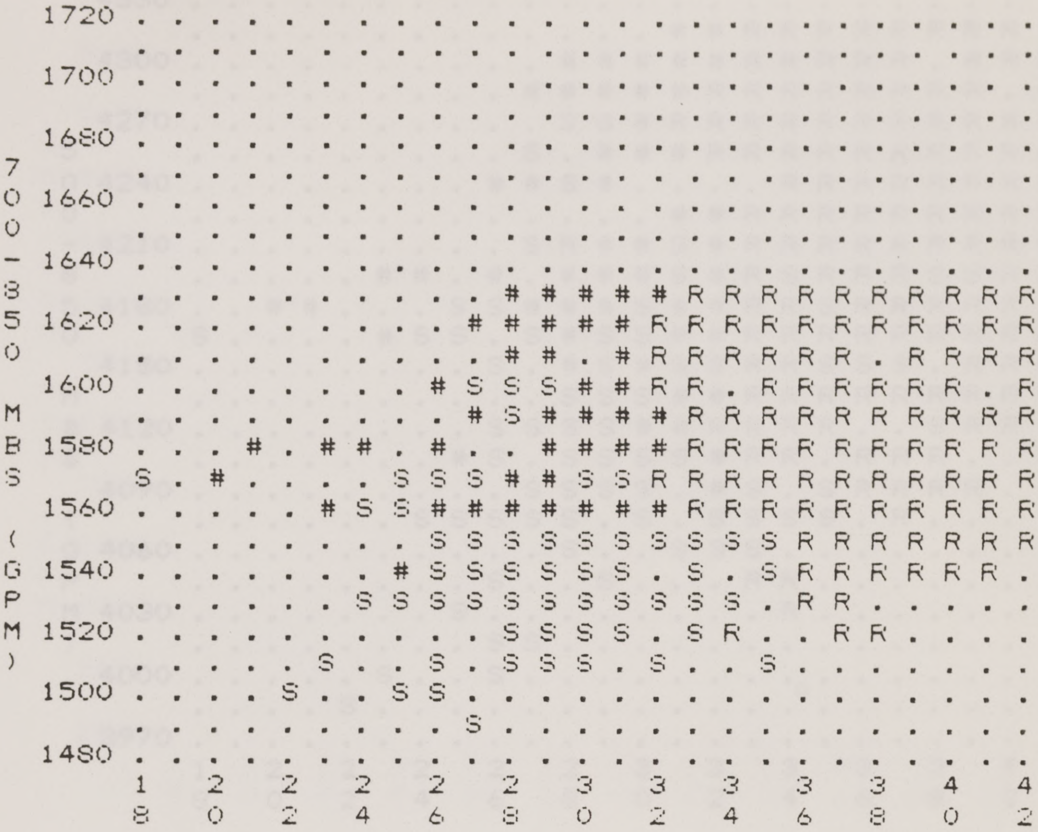
700-1000 mb Thickness versus Surface Temperature

```
  5680 . . . . . . . . . . . . . . . . . . . . . . . . .
       . . . . . . . . . . . . . . R R . R R . . . . . R
  5640 . . . . . . . . . . . . . # R R R R R R R R R R R
       . . . . . . . . . . # # # # # R R R . R R R R R .
5 5600 . . . . . . . . . . # # # # R R R R R R R R R R R
O      . . . . . . . . . # # # . . R R R R R R R R R R R
O 5560 . . . . . . . . . # S S # # R R R R R R R R R R R
-      . . . . . . . . . S . # # # R . R R R R R R R R R
1 5520 . . . . . . . . # # S . . # # R R R R R R R R R R
O      . . . . . . # . # . . # # S # R R R R R R R R R R
O 5480 . . . # . # . . . S . # # # # R R R R R R R R R .
O      . . # . . . . . S # # # S # S R R R R S R R R R R
  5440 S . . . . # S S S S S S S S # R R R R R R R R . .
M      . . . . . . . . S . # S # # S R R S . R R R R R .
B 5400 . . . . . . . . . S S S # # # S R S R S R R . . .
S      . . . . . . . # S S S S S S . S . S R R . R . . .
  5360 . . . . . . . . S S S S S S S S S . . R R . . . .
(      . . . . . . S S S S S . . . . R R S . R . . . . .
G 5320 . . . . . . S . . . S . . . S S R . . . . . . . .
P      . . . . . . . . . . . S . . . . . . . . . . . . .
M 5280 . . . . . . . S S . . . . . . . . . . . . . . . .
)      . . . . . . . . S S . . . . . . . . . . . . . . .
  5240 . . . . . S . . . . . . . . . . . . . . . . . . .
       . . . . S . . . . . . . . . . . . . . . . . . . .
  5200 . . . . . . . . . . . . . . . . . . . . . . . . .
       1   2   2   2   2   2   3   3   3   3   3   4   4
       8   0   2   4   6   8   0   2   4   6   8   0   2

                    TEMPERATURE (F)
```

```
CATEGORICAL DECISION GRAPH
 ('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416  PT:ALL
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A  Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.
```

Figure 25. Joint-Predictor Graph for Categorical Decisions for

500-1000 mb Thickness versus Surface Temperature



TEMPERATURE (F)

CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416 PT:ALL
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 26. Joint-Predictor Graph for Categorical Decisions for 700-850 mb Thickness versus Surface Temperature

```
  4330 . . . . . . . . . . . . . . . . . . . . . . . . .
       . . . . . . . . . . . . . # # R R R R R R R R . R
  4300 . . . . . . . . . . # # # # # R R R R R . R R R R
       . . . . . . . . . # # # # # R R R R R R R R . R R
  4270 . . . . . . . . . . S S # R R R R R R R R R R R R
5      . . . . . . . . . S . # # # R R R R R R R R R R R
0 4240 . . . . . . . . # # S # . . . . R R R R R R R R R
0      . . . . . . . . . . . . . # # R R R R R R R R R R
- 4210 . . . . . . . . . S R # # S # R R R R R R R R R R
8      . . . . . # # . # . # # # S # R S R R R S S R R R
5 4180 . . # # . . . S S # # # S # # R R S R R R R R R R
0      S . . . . # S S . S # S S # # R R R R R R R R R R
  4150 . . . . . . . . S . # S # S S R R S S S . R R R R
M      . . . . . . . . . . S S S # # R R R R R R R R R R
B 4120 . . . . . . . . S S S S # # R R R R . . S R R . .
S      . . . . . . . # S . S S S S # R R . R R R . . R .
  4090 . . . . . . . . . S S S S . # S . S R R R R . . .
(      . . . . . . S S S S S . S . S S S S . R . . . . .
G 4060 . . . . . . . . . . S . . S S S . . . . . . . . .
P      . . . . . . . . S . . S . . . R R . . . . . . . .
M 4030 . . . . . . . S . . . . . . . . R . . . . . . . .
)      . . . . . . . . S S . . . . . . . . . . . . . . .
  4000 . . . . . S . . S . . . . . . . . . . . . . . . .
       . . . . S . . . . . . . . . . . . . . . . . . . .
  3970 . . . . . . . . . . . . . . . . . . . . . . . . .
       1   2   2   2   2   2   3   3   3   3   3   4   4
       8   0   2   4   6   8   0   2   4   6   8   0   2

                 TEMPERATURE (F)

CATEGORICAL DECISION GRAPH
 ('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416  PT:ALL
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A  Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.
```

Figure 27. Joint-Predictor Graph for Categorical Decisions for

500-850 mb Thickness versus Surface Temperature

```
  2710 . . . . . . . . . . . . . . . . . . . . . . . . .
       . . . . . . . . . . . . . . . . . . . . . . . . .
  2690 . . . . . . . . . . . # # # R R R R R R . . . . .
       . . . . . . . . . . # # # # # R R R R R R R R R R
  2670 . . . . . . . . . S # # # # # R R R R R R R . R R
5      . . . . . . . . . # # S # R R R R R R R R R R R R
0 2650 . . . . . . . . . . . # # # R R R R R R R R R R R
0      . . . . . . . . # # S . . # # R R R R R R R R R R
- 2630 . . . . . . . . . . # # . S S S R R R R R R R R R
7      . . . . . . # . # # # # # S # R R R R S R R R R R
0 2610 . . . # . # S S S S S # S R # R S R R R R R R R R
0      S . # . . . . . S . # S S # # R R R R R R R R R R
  2590 . . . . . . . . . . # S # S # S R R R R R R R R R
M      . . . . . . . . S S S S S # # R R . R R S R R . R
B 2570 . . . . . . . . S . S # # . # R . . R R R R R R .
S      . . . . . . . # S S S # # # R S S S R R R . . R .
  2550 . . . . . . S S S S . S S # S R R R . R . R . . .
(      . . . . . . . . S S . S . S # S . . . . . . . . .
G 2530 . . . . . . . S S . S . . . . R . . . . . . . . .
P      . . . . . . . . . S . . . . . . R . . . . . . . .
M 2510 . . . . . . . . . . . . . . . . R . . . . . . . .
)      . . . . . . . . S . . . . . . . . . . . . . . . .
  2490 . . . . S S . . . . . . . . . . . . . . . . . . .
       . . . . S . . . . . . . . . . . . . . . . . . . .
  2470 . . . . . . . . . . . . . . . . . . . . . . . . .
       1   2   2   2   2   2   3   3   3   3   3   4   4
       8   0   2   4   6   8   0   2   4   6   8   0   2

                    TEMPERATURE (F)

CATEGORICAL DECISION GRAPH
 ('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 200
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416  PT:ALL
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A  Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.
```

Figure 28. Joint-Predictor Graph for Categorical Decisions for

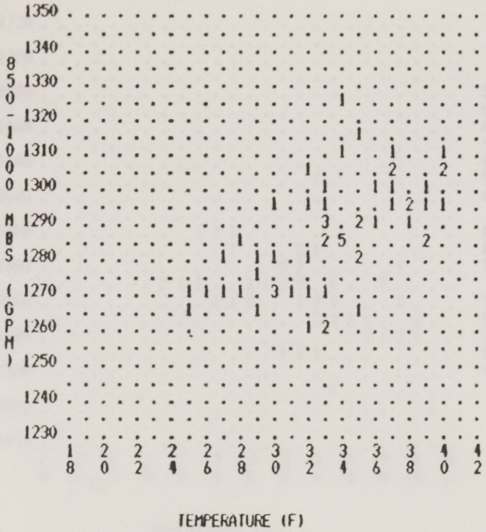
500-700 mb Thickness versus Surface Temperature

```
       1720 . . . . . . . . . . . . . . . . . . . . . . . . .
            . . . . . . . . . . . . . . . . . . . . . . . . .
       1700 . . . . . . . . . . . . . . . . . . . . . . . . .
            . . . . . . . . . . . . . . . . . . . . . . . . .
       1680 . . . . . . . . . . . . . . . . . . . . . . . . .
     7      . . . . . . . . . . . . . . . . . . . . . . . . .
     0 1660 . . . . . . . . . . . . . . . . . . . . . . . . .
     0      . . . . . . . . . . . . . . . . . . . . . . . . .
     - 1640 . . . . . . . . . . . . . . . . . . . . . . . . .
     8      . . . . . . . . . . . . . # # R # # R # R R R R R
     5 1620 . . . . . . . . . . . # # # # # # # # R # R R R R
     0      . . . . . . . . . . . R R R R R R R R R R R R R R
       1600 . . . . . . . . . . S # # # R R R R R R R R R R R
     M      . . . . . . R S R R R S R R R R R R R R R R R R .
     B 1580 . . . . . R R S R R # R R # R R R R R R R R R R R
     S      . . . . . S S S S # S R # # R R R R R R R R R R .
       1560 . . . . . . . S # # S # R R R R R R R R R . R R .
     (      . . . . . . . S S S S S S R R R R R R R . . R R .
     G 1540 . . . . . . . S S S S R R R R S R . R R . . R R .
     P      . . . . . S S S S S S S R . R R R . . . . . . . .
     M 1520 . . . . . . S . S S S S R . . . . . . . . . . . .
     )      . S S S S . S S S . S . . . . . . . . . . . . . .
       1500 . S . S S . . . . . . . . . . . . . . . . . . . .
            . . . . S . . . . . . . . . . . . . . . . . . . .
       1480 . . . . . . . . . . . . . . . . . . . . . . . . .
            1   1   1   1   1   1   1   1   1   1   1   1   1
            2   2   2   2   2   2   2   3   3   3   3   3   3
            3   4   5   6   7   8   9   0   1   2   3   4   5
            0   0   0   0   0   0   0   0   0   0   0   0   0
                          850-1000 MBS (GPM)
```

CATEGORICAL DECISION GRAPH
('S' IS FROZEN, '#' IS FREEZING, 'R' IS LIQUID)

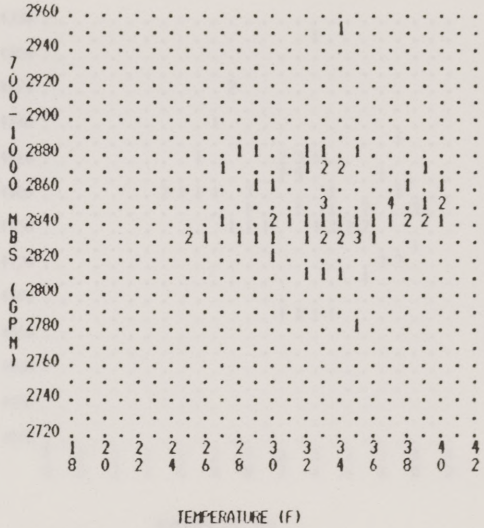
STATIONS:ALL / PRECIPITATION TYPE:FROZEN, FREEZING, & LIQUID
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES: 83
TOTAL HOURS SEARCHED: 1416
TOTAL HOURS OF PRECIPITATION TYPE: 1416 PT:ALL
MINIMUM ACCEPTABLE X= 1225 , USING AN X-INCREMENT OF: 5
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 29. Joint-Predictor Graph for Categorical Decisions for 700-850 mb Thickness versus 850-1000 mb Thickness



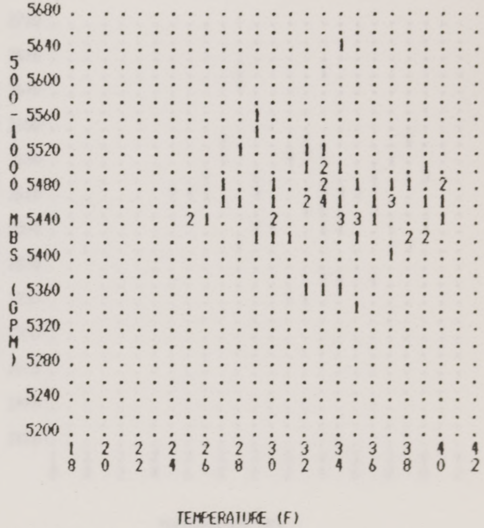
SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE: MIXED
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 62 PT: 16
GROUPING SCHEME: 1/2/3/4/5/6/16/16/16/16/16/16/13/16/16
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

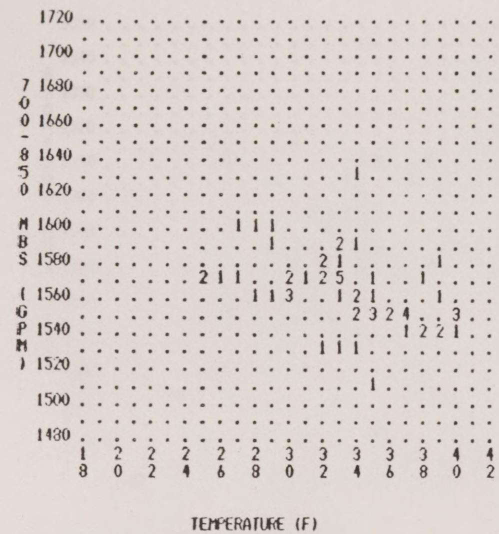
STATION:ALL/ PRECIPITATION TYPE: MIXED
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 62 PT: 16
GROUPING SCHEME: 1/2/3/4/5/6/16/16/16/16/16/16/13/16/16
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

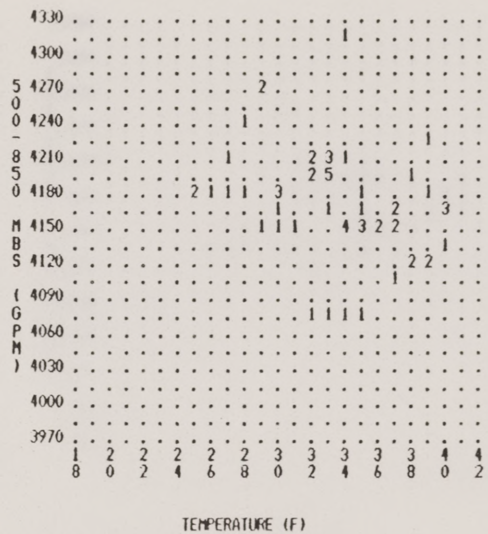
STATION:ALL/ PRECIPITATION TYPE: MIXED
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 62 PT: 16
GROUPING SCHEME: 1/2/3/4/5/6/16/16/16/16/16/16/13/16/16
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 30. Joint-Predictor Graphs for "Mixed" Precipitation for 850-1000 mb Thickness versus Surface Temperature; 700-1000 mb Thickness versus Surface Temperature; & 500-1000 mb Thickness versus Surface Temperature



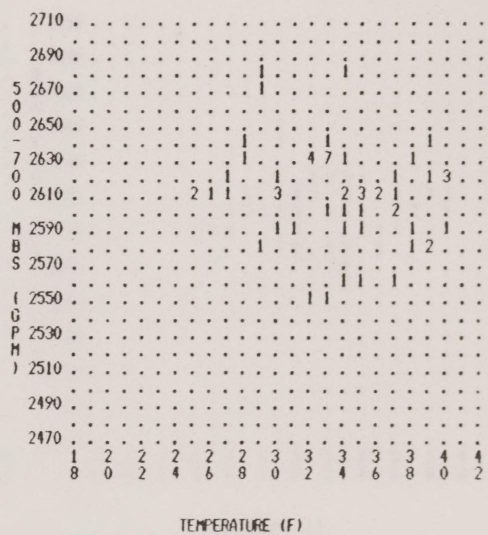
SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE: MIXED
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 62 PT: 16
GROUPING SCHEME: 1/2/3/4/5/6/16/16/16/16/16/16/13/16/16
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

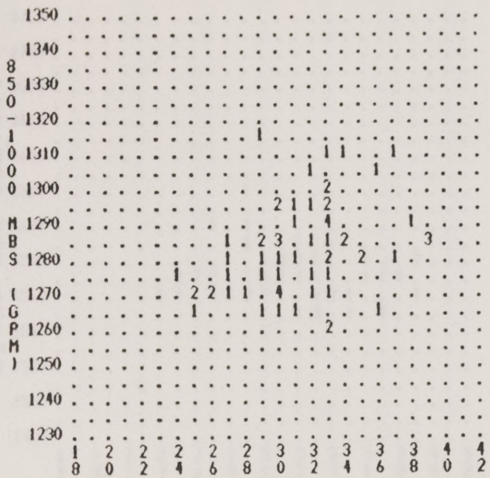
STATION:ALL/ PRECIPITATION TYPE: MIXED
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 62 PT: 16
GROUPING SCHEME: 1/2/3/4/5/6/16/16/16/16/16/16/13/16/16
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE: MIXED
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 62 PT: 16
GROUPING SCHEME: 1/2/3/4/5/6/16/16/16/16/16/16/13/16/16
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

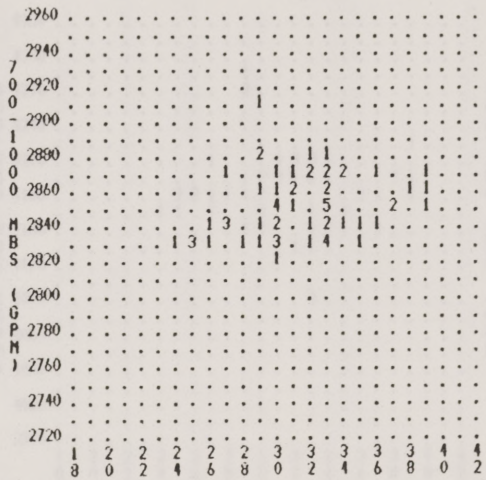
Figure 31. Joint-Predictor Graphs for "Mixed" Precipitation for 700-850 mb Thickness versus Surface Temperature; 500-850 mb Thickness versus Surface Temperature; & 500-700 mb Thickness versus Surface Temperature



TEMPERATURE (F)

SAMPLE FREQUENCIES

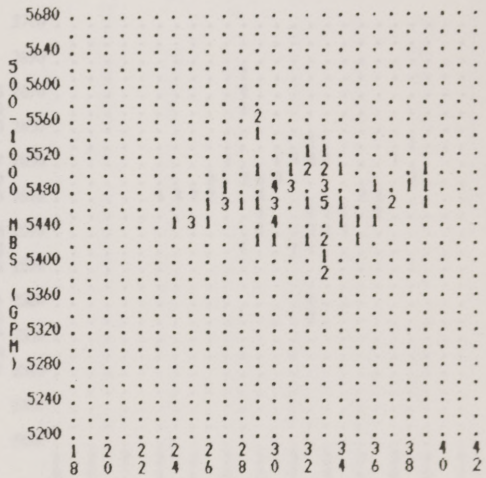
STATION:ALL/ PRECIPITATION TYPE:
MISCELLANEOUS: SEE GROUPING SCHEME
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 67 PT: 17
GROUPING SCHEME: 1/2/17/4/5/17/7/8/17/17/17/17/17/13/14/15
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1225 , USING A Y-INCREMENT OF: 5
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



TEMPERATURE (F)

SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE:
MISCELLANEOUS: SEE GROUPING SCHEME
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 67 PT: 17
GROUPING SCHEME: 1/2/17/4/5/17/7/8/17/17/17/17/17/13/14/15
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2710 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

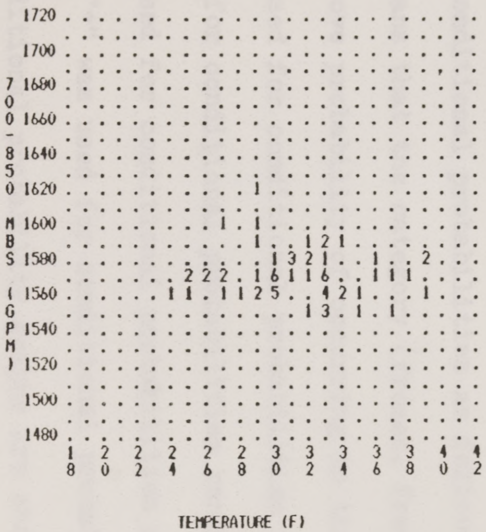


TEMPERATURE (F)

SAMPLE FREQUENCIES

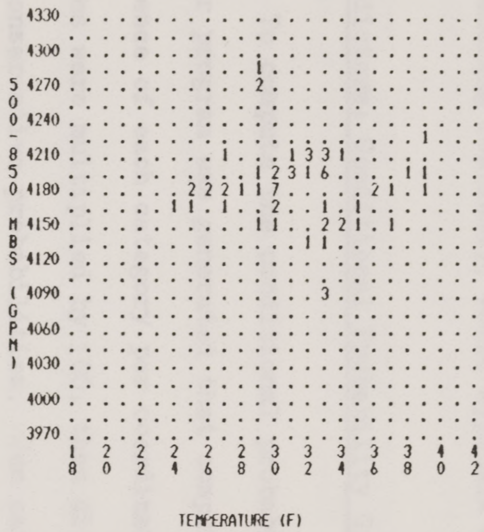
STATION:ALL/ PRECIPITATION TYPE:
MISCELLANEOUS: SEE GROUPING SCHEME
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 67 PT: 17
GROUPING SCHEME: 1/2/17/4/5/17/7/8/17/17/17/17/17/13/14/15
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 5180 , USING A Y-INCREMENT OF: 20
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 32. Joint-Predictor Graphs for "Ice Pellet" Precipitation for 850-1000 mb Thickness versus Surface Temperature; 700-1000 mb Thickness versus Surface Temperature; & 500-1000 mb Thickness versus Surface Temperature



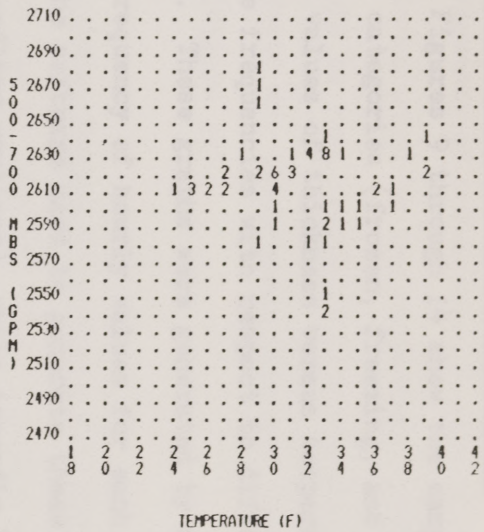
SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE:
MISCELLANEOUS: SEE GROUPING SCHEME
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 67 PT: 17
GROUPING SCHEME: 1/2/17/4/5/17/7/8/17/17/17/17/17/13/14/15
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 1470 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE:
MISCELLANEOUS: SEE GROUPING SCHEME
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 67 PT: 17
GROUPING SCHEME: 1/2/17/4/5/17/7/8/17/17/17/17/17/13/14/15
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 3955 , USING A Y-INCREMENT OF: 15
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.



SAMPLE FREQUENCIES

STATION:ALL/ PRECIPITATION TYPE:
MISCELLANEOUS: SEE GROUPING SCHEME
NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES= 0
TOTAL HOURS SEARCHED= 1416
TOTAL HOURS OF PRECIPITATION TYPE= 67 PT: 17
GROUPING SCHEME: 1/2/17/4/5/17/7/8/17/17/17/17/17/13/14/15
MINIMUM ACCEPTABLE X= 17 , USING AN X-INCREMENT OF: 1
MINIMUM ACCEPTABLE Y= 2460 , USING A Y-INCREMENT OF: 10
PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES.

Figure 33. Joint-Predictor Graphs for "Ice Pellet" Precipitation for 700-850 mb Thickness versus Surface Temperature; 500-850 mb Thickness versus Surface Temperature; & 500-700 mb Thickness versus Surface Temperature

Joint Predictors: Sample Frequency Graphs

Figures 9 through 14 show the sample frequencies of each of the three categories (frozen, freezing, and liquid) with respect to different values of thickness versus temperature while Figure 15 shows the sample frequencies with respect to different values of thickness versus thickness. These graphs were generated by a computer program that counted out the frequency of hourly values for each coordinate point. Appendix A shows the software used to generate these graphs (enclosed as an example of data handling routines), while Appendix B shows some of the sample data.

Joint Predictors: Conditional Probability Graphs and Categorical Decision Graphs

To compute the conditional probabilities of joint predictors, a computer program was generated that computed the relative frequency of occurrence of each category per coordinate point. These relative frequencies were multiplied by 100, then divided by 10 and truncated to give conservative probabilities. Ten categories were used that grouped conditional probabilities as follows: a conditional probability of "9" means that the category (frozen, freezing, or liquid) has a 90% or above probability of occurring in that certain coordinate point; "8" was used for conditional probabilities ranging from 80% to 89%; "7" was used for conditional probabilities ranging from 70% to 79%; . . . ; "1" was used for conditional probabilities ranging from 10% to 19%; and finally, "+" was used for conditional probabilities ranging from 01% to 09%. These conditional probability graphs are shown in Figures 16 through 22.

The categorical decision graphs for joint predictors are shown in Figures 23 through 28. These graphs were constructed by comparing the relative frequency of occurrence of each of the categories and labelling each coordinate point by the predominant category. These categorical graphs should be very useful in understanding the relationships between thickness vs. temperature (Figures 23-28) and of thickness vs. thickness (Figure 29).

Joint Predictors: Sample Frequencies for Mixed Precipitation

Of the 15 original classification categories used in this thesis, 8 were re-classified as "mixed" categories so that this analysis could be done. These "mixed" categories represent the concurrent intersection of either (1) frozen and liquid, or (2) frozen and freezing precipitation types. These sample frequencies, plotted on joint-frequency graphs, are shown in Figures 30 and 31.

Joint Predictors: Sample Frequencies for Ice Pellets (Sleet)

Of the 15 original classification categories used in this thesis, 6 were re-classified as "ice pellet" categories whether the ice pellets occurred exclusively or were observed with other types of precipitation. These "ice pellet" occurrences are part of the "frozen" data category mentioned in previous sections, but were isolated so that these special "ice pellet" graphs could be generated. Figures 32 and 33 show the sample frequencies for ice pellets.

VI. DISCUSSION OF RESULTS

Single Predictors and Joint Predictors for Frozen Precipitation

A summary of the results obtained from the graphical outputs of single predictors (Figures 2 through 8) are given in Table 5. Results show that the equal-probability value (50% value) for the 850-1000 mb thickness is 1281 gpm. This can be interpreted as saying that the frozen precipitation occurs with 1281 gpm or lower 850-1000 mb thickness values at least 50% of the time (assuming precipitation takes place). Similar conclusions can be made for the other values shown in Table 5.

Single predictors differ from joint predictors in that the latter makes use of two single predictors concurrently (such as thickness and surface temperature) to define a precipitation type. In joint predictor graphs one single predictor is fine-tuned by another.

Although joint predictors are not as easy to summarize as single predictors, from the graphical outputs shown in the previous section (in Figures 23-29), it is evident that the joint-predictors of 850-1000 mb thickness versus surface temperature far supersedes the other joint predictors since the cutoff values between snow and freezing rain, and the cutoff values between snow and rain are clearly defined. The 700-1000 mb thickness versus surface temperature graph is the next best graph of joint predictors. The higher the atmospheric strata one studies, the worse the results; the joint predictors of 700-850 mb, 500-850 mb, and 500-700 mb thicknesses proved to be rather poor joint

TABLE 5

SINGLE-PREDICTOR THESIS RESULTS FOR FROZEN PRECIPITATION

CONDITIONAL PROBABILITY (%)	850-1000 MB THICKNESS (GPM)	700-1000 MB THICKNESS (GPM)	500-1000 MB THICKNESS (GPM)	700-850 MB THICKNESS (GPM)	500-850 MB THICKNESS (GPM)	500-700 MB THICKNESS (GPM)	SURFACE TEMPERATURE (°F)
10	1296	2867	5489	1576	4207	2636	34
25	1288	2849	5459	1558	4160	2590	31
50	1281	2834	5396	1546	4098	2546	27
75	1267	2825	5381	1516	4082	2540	22
90	1254	2799	5312	1512	4074	2502	19

predictors. Moreover, the graph of thickness versus thickness, given in Figure 29 proved to be worse than if the surface temperature had been used as the second of the joint predictors.

Mixed Precipitation and Ice Pellets

Out of 1416 hourly precipitation occurrences in the thesis data base, only 62 hours of mixed precipitation occurred. Figures 30 and 31 show the sample frequencies of mixed precipitation as a function of thickness versus temperature. Moreover, out of 1416 hourly occurrences of precipitation, 67 hours of ice pellets occurred (whether occurring exclusively or occurring in mixed precipitation). Figures 32 and 33 show the sample frequencies of ice pellets or sleet as a function of thickness versus temperature. The results from these graphs are summarized in Table 6.

Not much difference was found in the thermal parameters responsible for mixed precipitation and ice-pellet precipitation as shown in Table 6. The only difference noted was that the median and range values were slightly lower in magnitude for the mixed precipitation when compared to the ice-pellet precipitation. This can be explained by the fact that mixed precipitation includes snow cases mixed with either rain or freezing rain, as opposed to the ice-pellet precipitation which includes no snow cases.

The most significant findings in Table 6 are that the median thickness values for ice pellets for the 850-1000 mb, 700-1000 mb, and the 500-1000 mb thicknesses may be used as the predictands for ice-pellet precipitation. It should be noted that no-one has ever found a method for

TABLE 6

SINGLE-PREDICTOR VALUES OF PRECIPITATION TYPE

THICK-NESS	MIXED PRECIPITATION		ICE-PELLET PRECIPITATION	
	Median	Range*	Median	Range*
850-1000	1284 gpm	1256-1315 gpm	1285 gpm	1256-1310 gpm
700-1000	2837 gpm	2801-2880 gpm	2843 gpm	2821-2880 gpm
500-1000	5446 gpm	5341-5560 gpm	5453 gpm	5361-5560 gpm
700-850	1557 gpm	1521-1600 gpm	1564 gpm	1541-1600 gpm
500-850	4163 gpm	4061-4270 gpm	4176 gpm	4076-4270 gpm
500-700	2607 gpm	2541-2680 gpm	2612 gpm	2531-2670 gpm
TEMP.	33.5 °F	25-40 °F	32.2 °F	25-39 °F

*Note: Range compromises the range of at least 96% of the data sample. By using this 96% range, extremes (and unrespresentative) values can be discarded.

forecasting ice pellets (sleet). As early as 1964, Boyden mentioned that "No way of forecasting sleet [ice pellets] appears to be known...".[24] Later in the same report he mentions "...no independent method of forecasting sleet was found... it is most likely to occur when rain and snow are equally probable...".[25] Since a 50% critical thickness value for frozen precipitation means that frozen precipitation and liquid precipitation are equally probable, the 50% values shown in Table 5 were compared with the corresponding median thickness values of Table 6. The results from this comparison show that for the 850-1000 mb thickness, the 50% value for frozen precipitation was 1281 gpm (the median value for ice pellets was 1285 gpm); for the 700-1000 mb thickness, the 50% value for frozen precipitation was 2834 gpm (the median value for ice pellets was 2843 gpm); finally, for the 500-1000 mb thickness, the 50% value for frozen precipitation was 5396 gpm (the median value for ice pellets was 5453 gpm). From these values, it can be seen that the difference between the 50% value for frozen precipitation and the median value for ice-pellets became progressively larger with increasing atmospheric depth. These values can be used to predict ice pellets as follows. Once a categorical decision has been made that the precipitation type will definitely be of the "frozen" type (as opposed to the alternatives of rain and freezing rain), the meteorologist can further define his forecast by inspecting the 500-1000 mb thickness. If this thickness is nearer to 5396 gpm, then a snow forecast is made; if the thickness is

---

[24] C.J. Boyden, "Snow Predictors," p. 359.

[25] Ibid., p. 364.

nearer to 5453 gpm, then an ice-pellet forecast is made. These results can be explained by the fact that ice pellets have to have an above-freezing layer in the higher levels of the atmosphere. If no above-freezing layer existed at the higher levels (e.g., 5000 feet to 18000 feet above mean sea level), then the precipitation would fall as snow. Therefore, a snow forecast differs from an ice-pellet forecast by the existence of a warm-layer in the upper-levels of the atmosphere. The existence of a warm-layer in the upper-levels of the atmosphere typifies an "overrunning" condition where warm moist air overrides the cold dry air at the surface. The value of the 500-1000 mb thickness can detect this warm layer aloft, while the value of the 850-1000 mb thickness does not.

In summary, the results of this paper show that low-level thicknesses (either 850-1000 mb or 700-1000 mb) can be used to determine the precipitation type (frozen, freezing, or liquid). If a frozen precipitation type is indicated by these low-level thicknesses, then a decision can be made whether this frozen precipitation will occur as snow or ice pellets by looking at the value of the 500-1000 mb thickness expected during the forecast period.

Comparison with Past Studies

Most of the early studies on snowfall or ice storms dealt with a descriptive study of the surface parameters involved in the occurrence. These studies used the surface temperature as the main predictor for the precipitation type. Not much mention was made of the upper atmosphere probably out of a lack of upper-level stations or a lack of data from the few stations that did exist.

One of the earliest studies found that used thickness and frozen precipitation was a study conducted in 1950 (author unknown). It was a descriptive study that dealt with a heavy-snow occurrence in Southern England. This study described the snow resulting from a cold upper-level "pool of cold air" with an associated 500-1000 mb thickness of 17010 geopotential feet (5185 gpm).[26] This value was not necessarily the cutoff value for snow and rain; nevertheless, the value was lower than the equal-probability value for snow of 5258 gpm as determined for the British Isles in a later study.[27]

The Wagner Study of 1957

One of the earliest and most cited studies in rain/snow discrimination is the study conducted by A. James Wagner of the Massachusetts Institute of Technology in 1957. Wagner used data from a large number of stations across the continental United States during two winter periods.[28] Wagner used a classification system similar to that used by the National Weather Service (NWS) except that Wagner used a dual-classification system. Wagner's dual-classification system groups all the freezing precipitation into the "liquid" category, while the NWS groups it into the "freezing" category. Wagner also groups all mixed precipitation into

---

[26]"Snowstorm During the Night of April 25-26, 1950," Meteorological Magazine 79 (August 1950): 229.

[27]Boyden, "Snow Predictors," p. 359.

[28]A. James Wagner, "Mean Temperature from 1000 MB to 500 MB as a Predictor of Precipitation Type," Bulletin American Meteorological Society 38 (December 1957): 584.

the "liquid" category; the NWS uses this same procedure, but this thesis groups the mixed precipitation into the "frozen" category. Therefore, Wagner's results theoretically will produce lower thicknesses for "frozen" precipitation since his sample data contain less "frozen" cases, proportionally, when compared to the remainder of his data. A few of Wagner's results are shown in Table 7.

Wagner was surprised at a few of the high thickness values he obtained from a few of the stations. He said:

> ...Also of interest are the relatively high values at Nashville, Little Rock, and Amarillo. Although these results are less reliable due to small data samples, it is unlikely that these thicknesses would all be anomalously high without some actual climatological cause.[29]

It should be noted that some of Wagner's results were based on samples as low as 23 (at Amarillo). This small data base cannot compare with the 1416 data samples used in this thesis for the Central Texas data. However, the equal-probability value for the 500-1000 mb thickness as determined in this study for Central Texas of 5396 gpm (see Table 5), compares more favorably with Wagner's values for Amarillo, Little Rock and Nashville than it does for the more northerly locations.

The Boyden Study of 1964

Boyden's study covered four winter periods when the snowfall was unusually heavy over the British Isles. The four winter seasons were 1955-56, 1957-58, 1961-62, and 1962-63. The total number of observations resulting for this particular study was 1406 with a breakdown of 1030 observations of rain, 300 of snow, and 76 of mixed rain and snow. The few cases of ice pellets were excluded from the 1406 data samples

---

[29]Ibid., p. 586.

TABLE 7

EQUAL-PROBABILITY VALUES (50%) AS DETERMINED BY WAGNER

STATION	EQUAL-PROBABILITY THICKNESS* FOR 500-1000 MBS (GPM)
Medford	~5300
Nantucket, New York, Norfolk	~5304
Amarillo	~5441
Little Rock	~5432
Nashville	~5425

Source: Wagner, James A. "Mean Temperature from 1000 MB to 500 MB as a Predictor of Precipitation Type." Bulletin American Meteorological Society 38 (December 1957): 584-90.

* These values have been converted from geopotential feet to geopotential meters.

by Boyden. In the Boyden study, the mixed precipitation cases were divided equally into the "snow" and the "rain" categories. Therefore, he used a dual-classification system. This thesis, conversely, uses a three-way classification system with "freezing" precipitation being the third category. The National Weather Service also uses a three-way classification system, unlike the Boyden study.

The results of the Boyden study are given in Table 8. The results of this thesis (from Table 5) are also shown, enclosed in brackets, in Table 8. The comparison shows that the 700-1000 mb and 500-1000 mb thickness values obtained for the British Isles are lower than the results obtained in this thesis. This would suggest that the column of air associated with frozen precipitation is colder through a greater depth over the British Isles than over Central Texas. This same effect was seen in the 500-1000 mb thickness values in the Wagner study. However, Boyden's values for 850-1000 mb thickness and surface temperature are both higher than thesis results because a deep column of cold air is unlikely to occur over Central Texas. In order to have frozen precipitation there must be very cold air in the 850-1000 mb layer as well as cold air at the surface. Some of the discrepancy may also be related to the lack of "freezing" precipitation in the Boyden study.

The Fortner-Roberts Study of 1971

The results of a 1971 study for Loring Air Force Base in Maine by Limon E. Fortner and Dale G. Roberts are shown in Table 9. Comparing the thesis results (given in brackets) with those obtained by Fortner and Roberts, reveals a marked difference in the conditional

TABLE 8

THERMAL PARAMETERS AS SINGLE PREDICTORS OF THE PROBABILITY OF FROZEN PRECIPITATION (SNOW) AS DETERMINED BY C.J. BOYDEN IN A 1964 STUDY FOR THE BRITISH ISLES

PROBABILITY OF SNOW (%)	850-1000 MB THICKNESS (GPM)	700-1000 MB THICKNESS (GPM)	500-1000 MB THICKNESS (GPM)	SURFACE TEMPERATURE (^{o}F)
90	1279 [1254]	2751 [2799]	5180 [5312]	31 [19]
50	1293 [1281]	2789 [2834]	5258 [5396]	35 [27]
10	1302 [1296]	2823 [2867]	5334 [5489]	39 [34]

SOURCE: Boyden, C.J. "A Comparison of Snow Predictors." The Meteorological Magazine 93(December 1964): 353-65.

Note: Figures enclosed in brackets indicate thesis results and are shown here for comparison.

TABLE 9

THERMAL PARAMETERS AS SINGLE PREDICTORS OF THE PROBABILITY OF FROZEN PRECIPITATION (SNOW) AS DETERMINED BY LIMON E. FORTNER AND DALE G. ROBERTS IN A 1971 STUDY FOR LORING AIR FORCE BASE, MAINE

PROBABILITY OF SNOW (%)	850-1000 MB THICKNESS (GPM)	700-1000 MB THICKNESS (GPM)	500-1000 MB THICKNESS (GPM)	700-850 MB THICKNESS (GPM)	SURFACE TEMPERATURE (^{o}F)
90	1290 [1254]	2800 [2799]	5320 [5312]	1500 [1512]	30 [19]
75	- -	- -	5350 [5381]	1515 [1516]	32 [22]
50	1300 [1281]	2830 [2834]	5400 [5396]	1530 [1546]	34 [27]
25	- -	- -	5430 [5459]	1545 [1558]	35 [31]
10	1310 [1296]	2860 [2867]	5480 [5489]	1555 [1576]	37 [34]

SOURCE: U.S. Air Force. Air Weather Service (MAC) 6th Weather Wing. A Resumé on the State of the Art for Snow Forecasting, by Charles L. Brenton, Jr., Technical Note 73-6. Washington, D.C.:USAF Environmental Technical Applications Center, July 1973.

Note: Figures enclosed in brackets indicate thesis results and are shown here for comparison.

probabilities obtained for the surface temperature and the 850-1000 mb thickness. The surface temperatures obtained from the 1971 study indicate that the equal-probability value (50%) for snow is 34°F while the thesis results indicate that the corresponding value for Central Texas is 27°F. All other probability values for temperature also show that the thesis results were lower than the values from the Fortner-Roberts study. The 850-1000 mb thickness obtained from the 1971 study indicates that the equal-probability value is 1300 gpm for snow while this study indicates that the corresponding value for Central Texas is 1281 gpm. All other probability values for the 850-1000 mb thickness also show that the thesis results were lower than the Fortner-Roberts results.

To investigate the importance of freezing rain in the derived thesis results it was decided to run a test which eliminated the freezing-rain occurrences from the Central Texas sample data by substituting fictitious snow occurrences in place of the freezing-rain occurrences. By using this substitution, a sample set of data was obtained for Central Texas where precipitation occurred as either liquid or frozen. The conditional probabilities for frozen precipitation in Central Texas were then re-evaluated by subtracting the conditional probabilities for liquid precipitation from 100% (± 1%). This subtraction resulted in the conditional probabilties for frozen precipitation given that no freezing precipitation occurs.

Comparing the adjusted conditional probabilities of frozen precipitation (snow) of the adjusted Central Texas data base and the Loring study we find much better agreement between the surface temperatures as well as the 850-1000 mb thicknesses. The adjusted 50% conditional probability for the Central Texas data base is $32^{\circ}F$ (the old value was $27^{\circ}F$). This adjusted conditional probability differs by only two degrees Fahrenheit from the $34^{\circ}F$ resulting from the Loring study. Likewise, for the 850-1000 mb thicknesses, the adjusted 50% value for the Central Texas area is 1292 gpm, which is somewhat closer to 1300 gpm (Loring value) than the earlier Central Texas value of 1281 gpm. Therefore, by eliminating the occurrence of freezing-precipitation occurrences from the Central Texas data, better agreement is found between the thesis results and the results from Loring Air Force Base. Is there any physical reason why freezing-rain occurrences are less frequent in the northern latitudes than they are in the southern latitudes ? This can be explained by the lack of significant warm air advection at the upper-levels for the northern latitudes, when compared to similar systems in the southern latitudes. This general concept was introduced earlier in the discussion of Boyden's study.

For very cold systems there is no intermediate precipitation type (freezing precipitation). The temperatures and thicknesses are low enough to allow liquid to change to frozen precipitation without the intermediate freezing precipitation occurring. We can see this phenomenon in the thesis results presented as joint-frequency graphs (see Figure 9), where for 700-1000 mb thicknesses less than or equal to 2800 gpm the result is either snow or rain since the thickness is too low (cold) to support the intermediate precipitation type, i.e., freezing. Therefore, it is possible that the 1971 Loring study reflects the fact that often thicknesses are too low to support precipitation of the freezing variety; this can account in part for the slight discrepancies between both studies.

Another study points out the differences that latitude makes on climatology of freezing-rain systems. According to Mr. Harms:

> Cold fronts undergo an appreciable change in slope as they reach the southern latitudes in the winter months, and there appears to be a direct relationship between the slope of the cold air and the distance of the heavy snow from the track of the surface low. This relationship probably applies to the width of the freezing rain band also. In the northern latitudes, the freezing rain band accompanying a major snowstorm is usually on the order of 25 to 30 n mi in width, whereas in the southern storms the band can be 50 n mi or more in width....[30]

This means that even when freezing precipitation occurs, the area covered by freezing precipitation may be as much as 50% less in the northern latitudes than in the southern latitudes since thicknesses are too low (cold) in the northern latitudes to support large areas of freezing precipitation.

Therefore, a combination of a lack of warm air advection and a relatively smaller area of freezing precipitation associated with each storm system in the northern latitudes can explain most of the differences between the thesis results and those of the 1971 study by Fornter and Roberts.

The Purvis Study of 1971

John G. Purvis determined the joint-predictor frequencies for snow, freezing rain, and rain cases for Greer, South Carolina

---

[30]Rheinhart W. Harms, "The Great Snowstorm of February 1973 over Georgia," Weatherwise 27 (October 1974): 195.

during the winters of 1968-69 and 1969-70.[31] The results from his study (as well as the comparable thesis results) are shown in Figure 34. Both of the graphs in Figure 34 show the predominant precipitation type as a function of both the 700-850 mb thickness and the 850-1000 mb thickness (it should be noted that the graph of the thesis results in Figure 34 is an exact duplicate of thesis Figure 29, on a smaller scale).

Comparison of both graphs in Figure 34 shows that although the precipitation types generally show the same patterns, i.e., snow occurs at the lower-left of the graphs while rain occurs at the upper-right of the graphs, a marked difference is seen in the freezing rain pattern. In the thesis results the freezing rain occurs with some rather high 700-850 mb thicknesses (as high as 1630 gpm), while in the Purvis graph, freezing rain is limited to 700-850 mb thicknesses as high as 1548 gpm. This difference in freezing rain occurrences can can be attributed to the fact that freezing rain cases in Central Texas are most of the time associated with an overrunning condition of warm, moist Gulf of Mexico air overriding cold polar air at the surface. This condition would tend to produce a warm layer at the 5000- to 10000-ft level of the atmosphere (approximate altitude of the 850 mb and the 700 mb surfaces, respectively) and thereby produce high thickness values. In contrast, the Purvis study uses data from a higher latitude (South Carolina). This higher latitude would tend to produce colder soundings over a greater depth of the atmosphere.

---

[31] U.S., Air Force, Air Weather Service (MAC) 6th Weather Wing, A Resumé on the State of the Art for Snow Forecasting, by Charles L. Brenton, Jr., Technical Note 73-6 (Washington, D.C.: USAF Environmental Technical Applications Center, July 1973), p. 26.

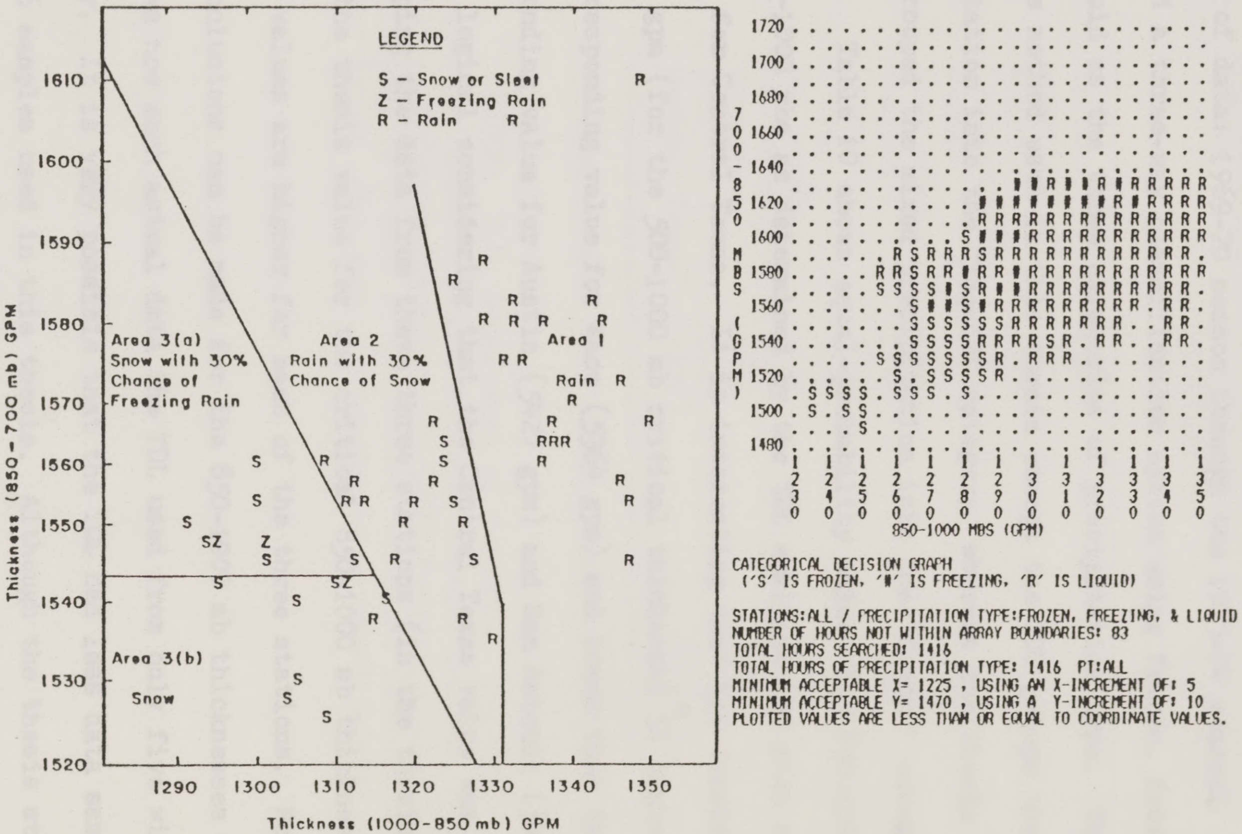


Figure 34. Comparison of Purvis' Results with Thesis Results
Source: U.S. Air Force. Air Weather Service (MAC) 6th Weather Wing. A Resumé on the State of the Art for Snow Forecasting, by Charles L. Brenton, Jr., Technical Note 73-6. Washington, D.C.: USAF Environmental Technical Applications Center, July 1973.

The TDL Study of 1975

The Techniques Development Laboratory (TDL) made a study of winter precipitation types across the United States during five winter seasons of data: 1969-70 season through the 1973-74 season. The TDL employed a three-way classification system using frozen, freezing, and liquid as the three categories of precipitation type. This is the same method used in this thesis except the TDL groups the mixed precipitation into the "liquid" category, whereas the thesis calculations grouped the mixed precipitation into the "frozen" category.

Table 10 shows equal-probability values for 850-1000 mbs and 500-1000 mbs as determined by the TDL analyses and also shows thesis results for Central Texas. It is interesting that the thesis result of 5396 gpm (for the 500-1000 mb critical thickness) is higher than the corresponding value for Waco (5364 gpm) and lower than the corresponding value for Austin (5427 gpm) and San Antonio (5431 gpm). This is logical considering that the Central Texas value was derived by grouping the data from these three stations (in the thesis). Although the thesis value for the critical 850-1000 mb thickness is 1281 gpm, the TDL values are higher for each of the three stations. No significant conclusions can be made for the 850-1000 mb thicknesses since it is not known how much actual data the TDL used from only five winter seasons of study. It is very possible that the TDL had less data samples than the 1416 samples used in this thesis. Although the thesis study also employed only five winter seasons of study, the thesis sample data may be more numerous than that of the TDL due to the twelve-fold increase in values obtained by interpolating upper-level values between synoptic times.

TABLE 10

EQUAL-PROBABILITY VALUES FOR STATIONS IN TEXAS AS DETERMINED BY THE TECHNIQUES DEVELOPMENT LABORATORY

STATION	850-1000 MB THICKNESS (GPM)	500-1000 MB THICKNESS (GPM)
Abilene	1297	5436
Amarillo	1333	5476
Austin	1304	5427
Corpus Christi	1317	5435
Dallas	1280	5370
Fort Worth	1280	5367
Houston	1312	5440
Lubbock	1323	5472
Lufkin	1303	5437
San Angelo	1296	5434
San Antonio	1308	5431
Victoria	1306	5397
Waco	1283	5364
Central Texas*	[1281]	[5396]

*Thesis results for Central Texas are shown in brackets.

SOURCE: U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Weather Service. Operational Probability of Frozen Precipitation (POF) Forecasts Based on Model Output Statistics, by Joseph R. Bocchieri, Technical Procedures Bulletin No. 146. Silver Spring, Maryland: Techniques Development Laboratory, August 28, 1975.

VII. FORECASTING APPLICATIONS OF THESIS RESULTS

Surface Temperature Guidance Issued by the TDL

Occurrences of both frozen and freezing precipitation types in the Central Texas area are relatively rare as compared to occurrences of liquid precipitation types. Once either frozen, or freezing precipitation occur, they are likely to occur in conjunction with fast-changing weather patterns. One problem with the surface temperature guidance issued by the Techniques Development Laboratory (TDL) of the National Weather Service is that the numerical equations used are not responsive enough to fast changing weather conditions.

The MOS (Model Output Statistics) approach is used in maximum/minimum temperature guidance issued by the TDL.[32] A deffiency associated with the use of climatic data in the MOS approach is that the maximum and minimum record temperatures for each single station are used in the data base as limits to the predicted value. For example, if the record low temperature for a certain day in Waco, Texas was 33°F, the temperature guidance would use this as a lower limit for the prediction of a minimum temperature, even though other meteorological conditions may indicate that a record-breaking temperature was likely. Since the MOS

---

[32] U.S., Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Automated Maximum/Minimum and 3-Hourly Surface Temperature Guidance, by Gary M. Carter and J. Paul Dallavale, Technical Procedures Bulletin No. 238 (Silver Spring, Maryland: Techniques Development Laboratory, May 22, 1978), p. 1.

output temperature are used to determine precipitation type[33], the PoPT output (Probability of Precipitation Type) is likely to be conservative in the area categorized as "frozen" and the area categorized as "freezing". Figure 35 shows a sample of the PoPT output available twice a day. The areas of frozen and freezing types may very well turn out to be somewhat larger than those shown on any PoPT output, as a result of the "conservative" nature of the MOS techniques.

Other predictors in the MOS temperature equations that may tend to dampen the effects of a fast-changing weather pattern (in favor of temperature continuity) are: (1) "Previous maximum temp", (2) "Previous minimum temp", and (3) yesterday's "snow cover".[34] Whenever a meteorologist makes a prediction of a certain meteorological parameter, it is likely to be derived at least in part by using continuity, i.e., the value of the parameter the day before. Once the forecasting meteorologist has this first-order approximation, he refines it by using common sense, experience, meteorological knowledge, and integration of other weather phenomena that can affect the parameter to be predicted. This refinement of the parameter results in the prediction for the next day. Likewise, the MOS equations use past values of temperatures as first-order approximations to be refined by other meteorological parameters. Unfortunately, most of the frozen and freezing precipitation cases in Central Texas occur with the passage of strong thickness gradients. Arctic cold fronts

---

[33] U.S., Operational Probability of Precipitation Type Forecasts, p. 1.

[34] Gary M. Carter et al., "Improved Automated Surface Temperature Guidance," Monthly Weather Review 107 (October 1979): 1265.

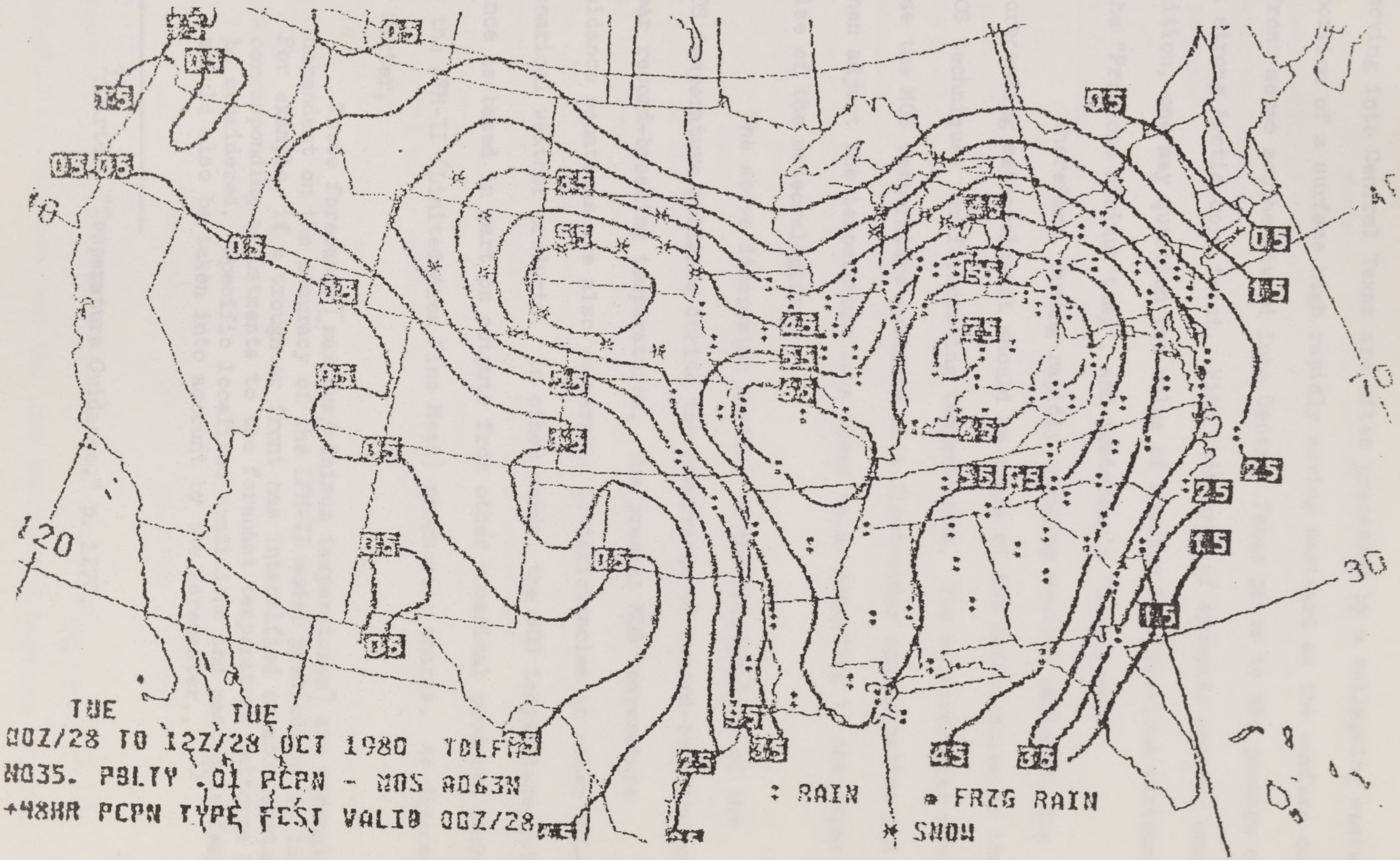


Figure 35. An Example of PoPT (Probability of Precipitation Type) Guidance
(Source: Difax Circuit [originating at Silver Spring, Maryland] October 25-26, 1980)

moving into Central Texas are often preceeded by a collapsing westward portion of a surface high rapidly moving eastward as the surface cold front moves southeastward into Central Texas prior to the passage of a strong Arctic cold front. With this type of synoptic weather condition, one may question the value of knowing the "Previous maximum temp", the "Previous minimum temp", and yesterday's "Snow cover".

Therefore, during rapidly changing weather patterns, the forecasting meteorologist should be aware of the deficiencies in the MOS techniques for forecasting temperatures. The meteorologist should use the MOS temperature guidance as a first-order approximation and then adjust the temperature to a lower value according to the expertise of the meteorologist.

The above discussion centers on the shortcomings of the MOS temperature guidance during the occurrence of record-breaking or near record-breaking temperatures. The present MOS temperature guidance equations are also vulnerable to deficiencies in other TDL-NWS numerical weather products. In other words, the MOS temperature guidance is based in part on outputs from other numerical products such as the LFM-II (Limited-Area Fine Mesh) prognostic charts. As discussed by Carter,

> These forecasts [maximum/minimum temperatures] are strongly dependent on the accuracy of the LFM-II model predictions as input. For example, if a trough or front has intensified or accelerated, corresponding adjustments to the forecast temperature patterns should be considered. Specific localized conditions and mesoscale features should also be taken into account by the forecaster....[35]

---

[35] Carter, "Temperature Guidance," p. 1270.

In summary, the MOS temperature guidance, issued twice daily (and routinely available to forecasting meteorologists) should be used with the knowledge of its limitations during fast-changing cold weather patterns.

Application of Thesis Results in Everyday Forecasting

One of the major objectives of this thesis is to obtain a precipitation-type forecast scheme for Central Texas which is convenient to use in everyday forecasting. It is anticipated that increased accuracy of precipitation-type forecasting will occur when the results of this thesis are used in conjunction with MOS temperature guidance and LFM-II prognostic charts provided by the National Weather Service.

Panel C of the LFM-II output (shown in Figure 36), is a display of the mean sea-level pressure (in millibars) and the 500-1000 mb thickness in geopotential meters. Moreover, the first panel of the LFM-II package, Panel A (shown in Figure 37), displays the 500 mb heights that are predicted by the LFM-II equations. Panel B (shown in Figure 38) shows the 700 mb heights that are forecast for the same time as the other panels. By interpolating the isopleth analysis for each of these panels, one can obtain point values for the 500-1000 mb thickness. Point values for the 700-1000 mb thickness can then be calculated from:

$$Z_{700-1000} = Z_{700} + [\, Z_{500-1000} - Z_{500}] \,, \qquad (11)$$

where $Z_{700-1000}$ is the 700-1000 mb thickness, $Z_{500-1000}$ is the 500-1000 mb thickness, and the term enclosed in brackets represents

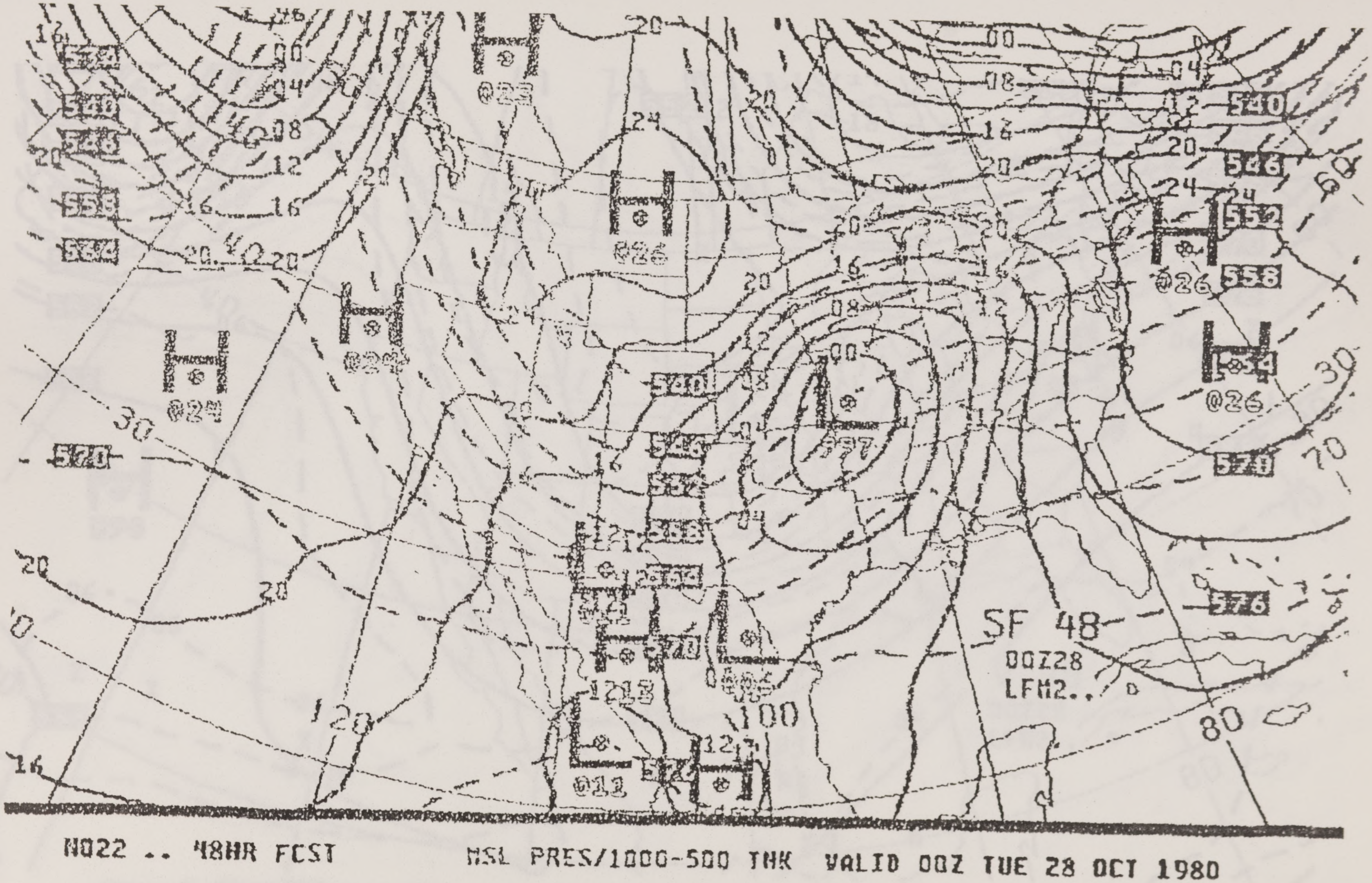


Figure 36.Panel C of the LFM-II Numerical Guidance Output
(Source: Difax Circuit [originating at Silver Spring, Maryland] October 25, 1980)

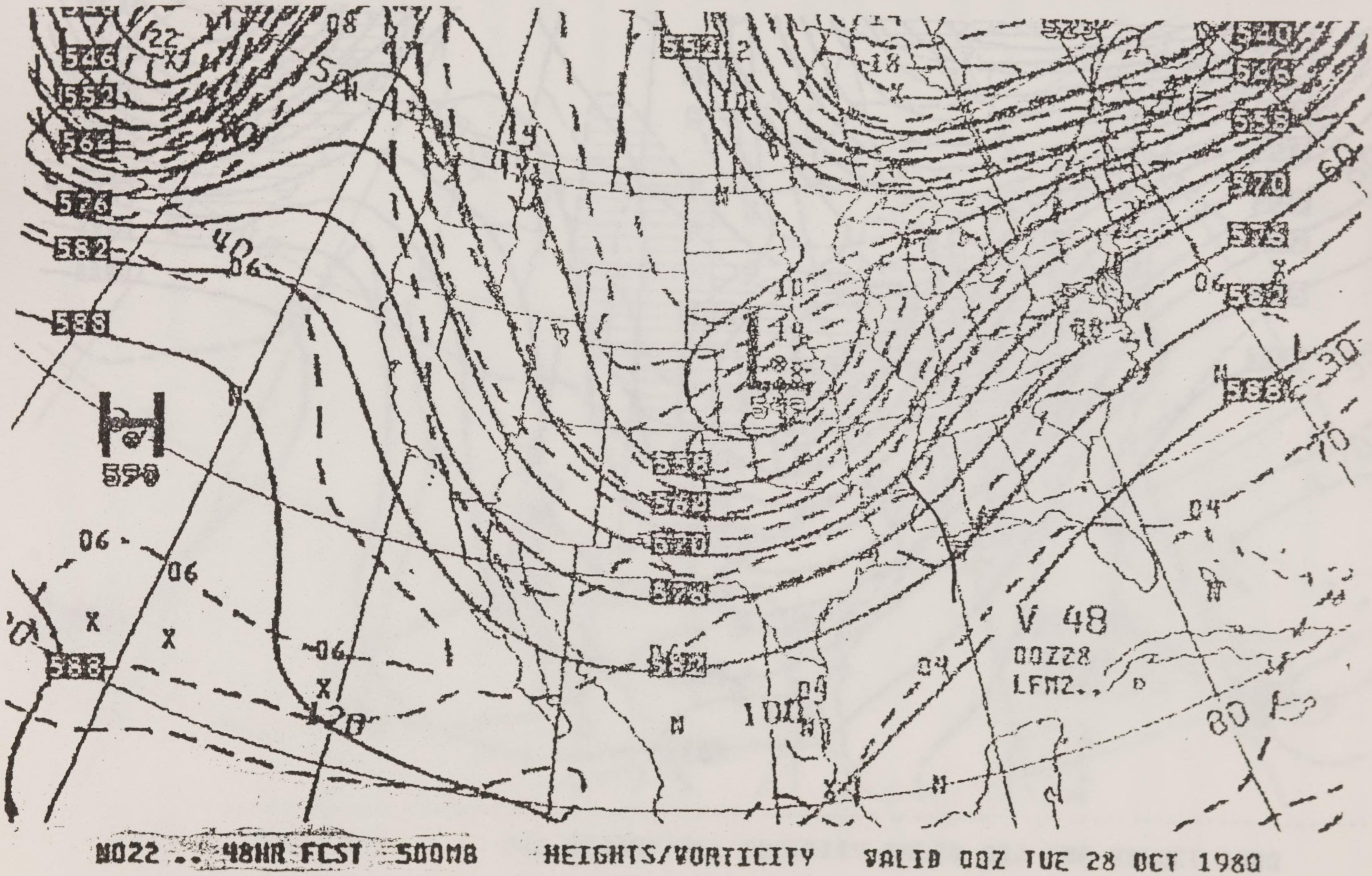


Figure 37. Panel A of the LFM-II Numerical Guidance Output
(Source: Difax Circuit [originating at Silver Spring, Maryland] October 25, 1980

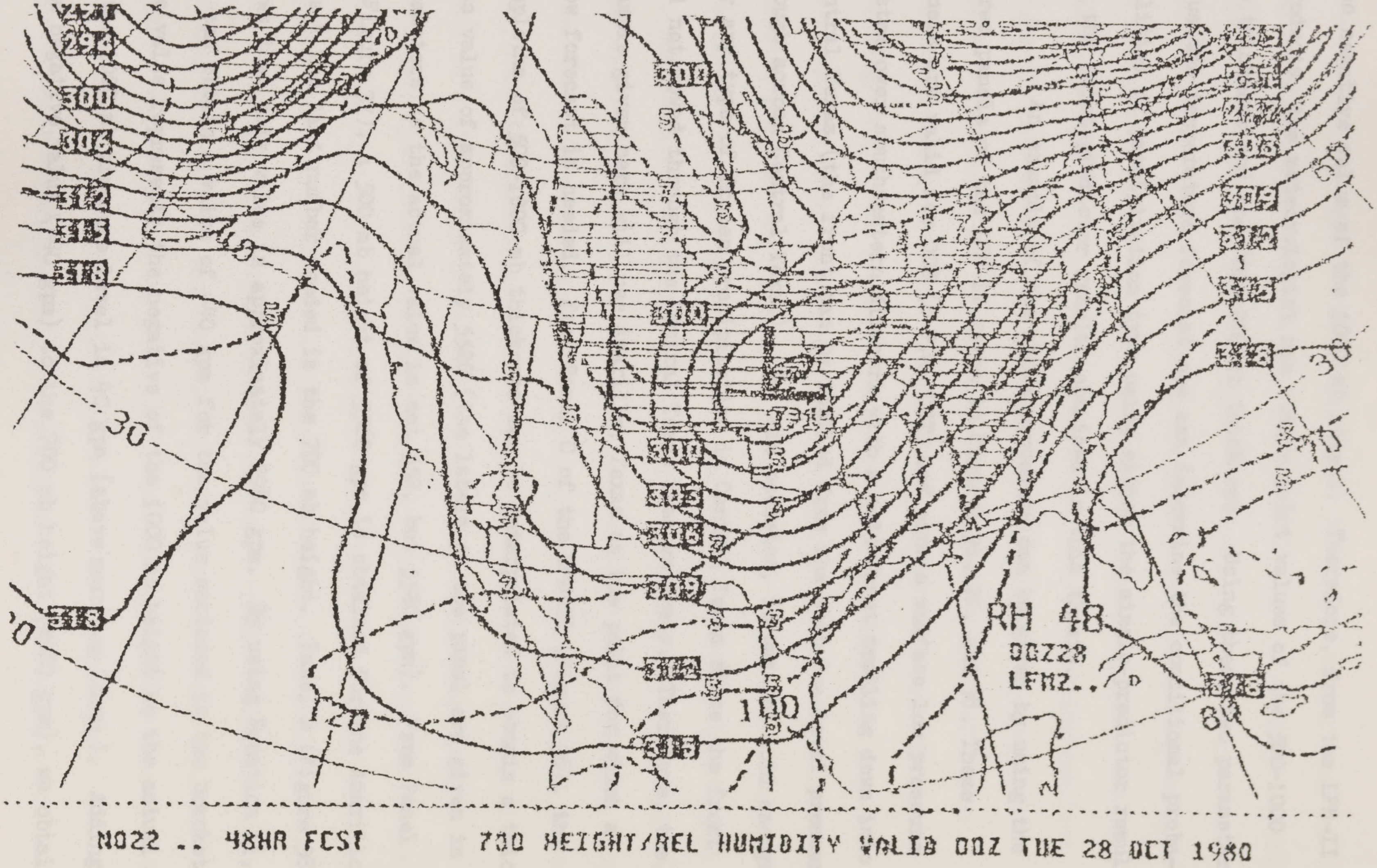


Figure 38. Panel B of the LFM-II Numerical Guidance Output
(Source: Difax Circuit [originating at Silver Spring, Maryland] October 25, 1980)

the negative value of the 1000 mb height. Therefore, from the LFM-II products, the meteorologist can obtain point values of the 500-1000 mb thickness and the 700-1000 mb thickness. Using these two parameters plus the temperature forecast one can determine the conditional probabilities of precipitation type using either the single-predictor results or the joint-predictor results obtained in this thesis.

An example of the above procedure can be given by using the three panels of the LFM-II given in Figures 36, 37, and 38. These panels are valid for 00Z (6 P.M. CST) and show a surface low pressure system over southwestern Missouri with a cold front trailing down into Central Texas (the front can be implied from the Mean Sea Level pressure trough across Central Texas). On this occasion, it was not cold enough for any type of frozen precipitation in Central Texas since the front had not moved through the Central Texas area entirely. Therefore, the example given here will use Amarillo, Texas as the point for which a snow forecast is needed. From Panel C of the LFM-II (Figure 36), the isopleths of 500-1000 mb thickness can be interpolated to obtain a thickness value of approximately 5520 (the labels on the panel are given in decameters so the actual value is not 552, but 5520 gpm). From Panel A (Figure 37), a 500 mb height of 5560 gpm is obtained for the Amarillo area. The last number needed is the 700 mb height. Panel B (Figure 38) shows that this value is approximately 2980 gpm. By using Equation 11, one can obtain a value of -40 gpm for the value enclosed in the brackets. This value represents the negative of the 1000 mb height so the actual height of the 1000 mb pressure level is 40 gpm (above mean sea level). Adding this negative value (-40 gpm) to the 700 mb height (2980 gpm), we obtain a value for the 700-1000 mb thickness of 2940 gpm. We now have two values for Amarillo, Texas for the 28th October 1980: (1) 500-1000 mb thickness equals 5520 gpm, and (2) 700-1000 mb thickness equals 2940 gpm from calculations. These two values are single predictors and can be used to obtain conditional probabilities for snow, freezing rain, and rain. Using the thesis results obtained for the 500-1000 mb thickness (see Figure 4), and assuming that these Central Texas thesis results can apply to Amarillo, one obtains a conditional probability of 2% for frozen precipitation, 12% for freezing precipitation, and 85% for liquid precipitation (these three conditional probabilities only add up to 99% due to the conservative rounding-off routines built into the computer programs that generated these graphs). Furthermore, using the thesis results obtained for the 700-1000 mb thickness (see Figure 3), one obtains a conditional probability of 0% for frozen precipitation, 26% for freezing precipitation, and 73% for liquid precipitation. From these two single predictors (500-1000 mb thickness & 700-1000 mb thickness), the forecasting meteorologist can make the decision that if there is a 100% probability that precipitation will occur during the time period covering 00Z 28th October 1980, then he should categorically state that the precipitation is likely to fall as rain. The above example shows that there is a slight chance of freezing precipitation. The forecasting meteorologist should predict a temperature valid at 00Z 28th October 1980 and use this as the final refinement to his forecast. Figure 8 shows that if the predicted temperature is 33°F or above, the chances for freezing precipitation are zero. In conclusion, in the above example the forecasting meteorologist used two single predictors (thicknesses) to derive a forecast, and then used a third single predictor (temperature) to ultimately determine the precipitation type, in this case, rain.

A word of caution is necessary at this point. The National Weather Service forecasts only mention the probability of measurable precipitation during 12-hour periods. The precipitation forecast is qualified by the kind of precipitation type, and no mention is made of the conditional probability of the precipitation type or the absolute probability of the precipitation type. In the above example, the forecast may be stated as follows: "Cloudy and cold with rain early this evening possibly becoming freezing rain later tonight...low tonight 32°F... chance of measurable precipitation 100% tonight...". If the meteorologist is certain that the surface temperature will remain above freezing, then the forecast would be stated as follows: "Cloudy and cold with rain this evening...low tonight 33°F... chance of measurable precipitation 100% tonight...". Although snow is possible with a surface temperature of 32°F or 33°F, the forecasting meteorologist doesn not mention this in his forecast, since the single predictors of 500-1000 mb thickness and 700-1000 mb thickness indicated that the conditional probabilities for frozen precipitation were 2% and 0%, respectively.

The LFM-II product that is transmitted twice a day is valid for 12, 24, 36, and 48 hours after the initial time of the data input. During fast-changing weather patterns, the thermal parameters of the atmosphere are constantly changing, so the LFM-II products do not necessarily show the maximum or minimum values of the meteorological parameters to be expected. For example, if a trough of low pressure moves through the station 18 hours after the initial data input into the LFM-II prog package, then the 12- and 24-hour LFM-II prog outputs will not represent the lowest thicknesses that will be experienced by the station during the forecast period. This is an important point that should be kept in mind by forecasters.

VIII. SUMMARY

This thesis used upper-level and surface data (from five winter seasons) in an objective study to determine the thermal-parameter values necessary to produce frozen and freezing precipitation types in the Central Texas area. Surface data from Waco, Austin, and San Antonio, Texas were used, while upper-level data had to be graphically interpolated for the Central Texas area from analyses of upper-level data from nearby stations. The seven thermal parameters calculated were the: (1) 850-1000 mb thickness, (2) 700-1000 mb thickness, (3) 500-1000 mb thickness, (4) 700-850 mb thickness, (5) 500-850 mb thickness, (6) 500-700 mb thickness, and the (7) surface temperature. The sample frequencies and the conditional probabilities (as determined by relative frequencies) of "frozen", "freezing", and "liquid" precipitation types were determined and plotted in graphical form in Figures 2 through 33. These thesis results provide a climatic data base on which a forecasting meteorologist can base his winter-time forecasts of snow, freezing rain, or rain.

When thesis results were compared to past studies of the 1950s and 1960s, the critical-thickness values determined from thesis calculations were somewhat higher than the historical values from the studies of the 1950s and the 1960s. This difference in values can be attributed to: (1) colder mean-temperature soundings in the historical studies, (2) less data analyzed in the historical studies, and (3) different (and less accurate) grouping schemes used in the historical studies.

Very similar results were obtained when thesis values were compared to values obtained in a 1975 study by the National Weather Service's Techniques Development Laboratory. Even though the thesis calculations grouped "mixed" precipitation into the "frozen" precipitation category (the National Weather Service groups it into the "liquid" category), very similar critical-thickness values were obtained (see Table 10).

Perhaps one of the most important findings of this thesis is that a method for forecasting sleet (ice pellets) may have been found. Once a categorical decision has been made by the forecasting meteorologist that the precipitation type will be frozen (as opposed to the other two alternatives: freezing, or liquid), the meteorologist can further refine his forecast by indicating what kind of "frozen" precipitation should be expected. He can determine the kind of "frozen" precipitation by inspecting the 500-1000 mb thickness. If this thickness is nearer to 5396 gpm, then a snow forecast is made; if the thickness is nearer to 5453 gpm, then ice pellets should be predicted.

The values of the single-predictor conditional probabilities obtained in this thesis (shown in Figures 2 through 8) may be improved somewhat by using non-linear regression analysis to compensate for the lack of smoothness in the conditional-probability distribution. This non-linear regression analysis uses a logit model as a weighting-scheme to smooth-out the distribution of values.[36] This weighting-scheme does alter the true conditional probabilities as determined by the sample data used in a study, so this alteration should be considered

---

[36]William M. Brelsford and Richard H. Jones, "Estimating Probabilities," Monthly Weather Review 95 (August 1967): 570-76.

before the non-linear regression analysis is used.

Future studies for winter-precipitation types in Texas can use stations that are upper-level sounding stations, such as Victoria, Abilene, and Amarillo, Texas. Using these sounding stations would eliminate the very time-consuming upper-level analyses done in this thesis and would also eliminate any errors that may be introduced by the graphical interpolation of the upper-level data. If such studies are conducted, the meteorologist should be careful in using data from South Central Texas (Victoria), or Northwest Texas (Abilene & Amarillo) and applying these results to the Central Texas area. Past studies have shown that critical-thickness values are dependent on geographical factors such as altitude and latitude.

It is hoped that results from this thesis will be used by forecasters and that these results will help eliminate some of the guesswork presently used in forecasting snow, freezing rain, and rain during the winter months in the Central Texas area.

APPENDIX A-EXAMPLE OF A SOFTWARE ROUTINE

This software program was used to obtain the joint-predictor graphical outputs. It is written in the Alpha-Basic computer language.

```
! ****************** GRAPH2.BAS **********************
! THIS PROGRAM WILL PRINT OUT A JOINT FREQUENCY GRAPH.
! RELATED PROGRAMS:CALC.BAS, INTO.BAS,TRNSFR.CMD,MAXI.BAS,
! CHOOSE.BAS, SUM.BAS
! LAST UPDATE ON 9/30/80 & 10/4/80 & 10/19/80 & 10/20/80
                        STRSIZ 45              !& 10/22/80
                        DIM A(25,25)           !& 10/23/80
                        DIM XLBL$(26)
                        DIM YLBL$(26)
! THE STORAGE MATRIX "A" IS INITIALIZED AS A ZERO MATRIX BY
! THE ABOVE DIMENSION STATEMENT SO NO LOOP-INITIALIZATION IS
! NEEDED.
INPUT "WHAT IS THE PRECIPITATION TYPE ?=";PT'IN !AN INPUT OF 16 IS FOR MIXED
! A PT'IN OF 17 MEANS MISCELLANEOUS, LOOK AT CLASSIFICATION/GROUPING SCHEME
!INPUT "WHAT IS THE X-PARAMETER (TF,DZ81,DZ71,DZ51,DZ78,DZ58,DZ57)";X'PAR$
  X'PAR$="TF"
!INPUT "WHAT IS THE Y-PARAMETER (TF,DZ81,DZ71,DZ51,DZ78,DZ58,DZ57)";Y'PAR$
  Y'PAR$="DZ58"
!INPUT "WHAT IS XLOLIM=";XLOLIM
  XLOLIM=18
!INPUT "WHAT IS YLOLIM=";YLOLIM
  YLOLIM=3970
!INPUT "WHAT IS X'INC=";X'INC
  X'INC=1
!INPUT "WHAT IS Y'INC=";Y'INC
  Y'INC=15
JAIL:
INPUT "WHAT IS THE STATION?=";STA$

              IF STA$="ACT" THEN GOTO PIN
              IF STA$="AUS" THEN GOTO PIN
              IF STA$="SAT" THEN GOTO PIN
 PRINT "YOU HAVE ENTERED A WRONG STATION DESIGNATION":GOTO JAIL

PIN:

! AFTER INPUTTING ORIGIN AND INCREMENTS, THE GRAPH LABELS CAN
! BE CONSTRUCTED.

                  ! XLBL$(1) IS THE FIRST LABEL ON THE X AXIS.
                  XLBL$(1)=STR$(XLOLIM)
                  XLBL$(2)="    "

             FOR R=3 TO 25 STEP 2
             XLBL$(R)=STR$(XLOLIM+((R-1) *X'INC))
             XLBL$(R+1)="    "  ! NOTE:THIS INPUTS A BLANK LABEL
             NEXT R
             ! THE LAST LABEL(26) IS BLANK

                  ! YLBL$(1) IS THE FIRST LABEL ON THE Y AXIX.
                  YLBL$(1)=STR$(YLOLIM)
                  YLBL$(2)="    "
             FOR C=3 TO 25 STEP 2
             YLBL$(C)=STR$(YLOLIM+((C-1)*Y'INC))
             YLBL$(C+1)="    "  ! NOTE:THIS INPUTS A BLANK LABEL
             NEXT C
             ! THE LAST LABEL (26) IS BLANK
START'FILE'INP:
                        TOTAL'COUNT=0
                        PT'COUNT=0
                        MISFIT=0
```

APPENDIX A (Continued)

```
! THE NEXT STATEMENT OPENS UP THE DATA FILE FOR EACH OF THE STATIONS.
IF STA$="ACT" THEN FILNAM$="CALC.DAT"
IF STA$="AUS" THEN FILNAM$="CALC1.DAT"
IF STA$="SAT" THEN FILNAM$="CALC2.DAT"
OPEN #2,FILNAM$,INPUT
INPUT #2,DUMMY$

TOP:
PRINT TOTAL'COUNT
TOP'P:     ! I DON'T WANT TO PRINT TOTAL'COUNT ON THE VIDEO TERMINAL WHEN
           ! H8>1000000 SINCE IT'LL MERELY PRINT OUT THE SAME NUMBER AS
           ! BEFORE, SO I'M BRANCHING INTO TOP'P.
INPUT #2,H8
IF H8>1000000 THEN GOTO TOP'P
IF H8=0 THEN GOTO PRINT'IN'FIL

          TOTAL'COUNT=TOTAL'COUNT+1
! THE ABOVE COUNTER DOESN'T INCLUDE THE DUMMY HEADING NOR
! STATIONS-DATES

INPUT #2, H7,H5,PT,TF,H1,DZ81,DZ71,DZ51,DZ78,DZ58,DZ57
! NOTE THE FOLLOWING ARE A CLASSIFICATION/GROUPING SCHEME THAT CAN BE
! CHANGED DEPENDING ON WHAT WE ARE ACTUALLY LOOKING FOR.
GROUP$="1/1/1/4/5/1/1/1/1/1/1/1/1/1/1"
IF PT=1 THEN PT=1:GOTO CLASS
IF PT=2 THEN PT=1:GOTO CLASS
IF PT=3 THEN PT=1:GOTO CLASS
IF PT=4 THEN PT=4:GOTO CLASS
IF PT=5 THEN PT=5:GOTO CLASS
IF PT=6 THEN PT=1:GOTO CLASS
IF PT=7 THEN PT=1:GOTO CLASS
IF PT=8 THEN PT=1:GOTO CLASS
IF PT=9 THEN PT=1:GOTO CLASS
IF PT=10 THEN PT=1:GOTO CLASS
IF PT=11 THEN PT=1:GOTO CLASS
IF PT=12 THEN PT=1:GOTO CLASS
IF PT=13 THEN PT=1:GOTO CLASS
IF PT=14 THEN PT=1:GOTO CLASS
IF PT=15 THEN PT=1:GOTO CLASS
CLASS:
IF PT<>PT'IN THEN GOTO TOP

          PT'COUNT=PT'COUNT+1
!NOTE: FOR EACH DATA LINE, X,Y EACH HAS A UNIQUE VALUE WHICH IS
!TESTED IN THE NEXT SET OF LOOPS.

GOSUB PARA'METER
IF PT'IN=1 THEN PRINT "FROZEN":GOTO RIO
IF PT'IN=4 THEN PRINT "FREEZING":GOTO RIO
IF PT'IN=5 THEN PRINT "LIQUID":GOTO RIO
IF PT'IN=16 THEN PRINT "MIXED"
IF PT'IN=17 THEN PRINT "MISCELLANEOUS"
          RIO:
! THE NEXT LOOPS FIND A PLACE IN THE ARRAY FOR EACH HOUR OF "PT"
! THAT IS READ IN.
! HERE I'M STORING CHANGING Y VALUES INTO INCREMENTAL J'S, RESULTING
! IN HIGH VALUES OF X & Y BEING STORED IN HIGH SUBSCRIPTED VARIABLES.
! THE MISFIT STATEMENT IS LOCATED BEFORE THE ITERATIONS TO SAVE TIME
! FOR THOSE VALUES OUTSIDE THE ARRAY. OTHERWISE, 625 ITERATIONS WOULD
! HAVE TO BE MADE FOR ONE VALUE TO BE PUT OUTSIDE THE ARRAY.

IF X>(24*X'INC) THEN MISFIT=MISFIT+1: GOTO TOP
IF Y>(24*Y'INC) THEN MISFIT=MISFIT+1: GOTO TOP

FOR I=25 TO 1 STEP -1
  II=I-1: III=I-2
FOR J=25 TO 1 STEP -1
  JJ=J-1: JJJ=J-2
IF X<=(II*X'INC) IF X>(III*X'INC) IF Y<=(JJ*Y'INC) IF Y>(JJJ*Y'INC) THEN A(I,J)=A(I,J)+1:GOTO TOP
```

APPENDIX A (Continued)

```
NEXT J
NEXT I
MISFIT=MISFIT+1
? "IF YOU'RE HERE YOU'RE VALUE IS BELOW THE COORDINATE VALUES OF THE MATRIX."
KKK=1
GOTO TOP
PRINT'IN'FIL:
CLOSE #2
IF STA$="ACT" IF PT'IN=1  THEN OPEN #1,"GRA101.FIL",OUTPUT
IF STA$="ACT" IF PT'IN=4  THEN OPEN #1,"GRA104.FIL",OUTPUT
IF STA$="ACT" IF PT'IN=5  THEN OPEN #1,"GRA105.FIL",OUTPUT
IF STA$="ACT" IF PT'IN=16 THEN OPEN #1,"GRA116.FIL",OUTPUT
IF STA$="ACT" IF PT'IN=17 THEN OPEN #1,"GRA117.FIL",OUTPUT
IF STA$="AUS" IF PT'IN=1  THEN OPEN #1,"GRA201.FIL",OUTPUT
IF STA$="AUS" IF PT'IN=4  THEN OPEN #1,"GRA204.FIL",OUTPUT
IF STA$="AUS" IF PT'IN=5  THEN OPEN #1,"GRA205.FIL",OUTPUT
IF STA$="AUS" IF PT'IN=16 THEN OPEN #1,"GRA216.FIL",OUTPUT
IF STA$="AUS" IF PT'IN=17 THEN OPEN #1,"GRA217.FIL",OUTPUT
IF STA$="SAT" IF PT'IN=1  THEN OPEN #1,"GRA301.FIL",OUTPUT
IF STA$="SAT" IF PT'IN=4  THEN OPEN #1,"GRA304.FIL",OUTPUT
IF STA$="SAT" IF PT'IN=5  THEN OPEN #1,"GRA305.FIL",OUTPUT
IF STA$="SAT" IF PT'IN=16 THEN OPEN #1,"GRA316.FIL",OUTPUT
IF STA$="SAT" IF PT'IN=17 THEN OPEN #1,"GRA317.FIL",OUTPUT
FOR J=25 TO 1 STEP -1 ! HIGHEST Y VALUES ARE PRINTED FIRST WITH
FOR I=1 TO 25         ! LOWEST X VALUES
  A$=STR$(A(I,J))   !NOTE THAT A$ IS NOT A MATRIX. IT CHANGES VALUES
  IF A(I,J)=0 THEN A$="."         !AT EACH ITERATION
PRIN:
GOSUB WORDS   ! THE "WORDS" SUBROUTINE LABELS THE ABSCISSA AND ORDINATE
! HERE I'M PRINTING OUT THE CHANGING X VALUES ACROSS THE PAGE SINCE I'S
! GET INCREMENTED FROM 1 TO 25.
                IF A(I,J)>9 THEN GOTO TENS
IF I=1 THEN ? #1,ORDINA$[J;1];SPACE(1);YLBL$(J);SPACE(1);A$;SPACE(1);:GOTO THERE
IF I=25 THEN ? #1,A$:GOTO THERE
PRINT #1, A$;SPACE(1);:GOTO THERE
! NOTE, THE SEMICOLON ABOVE MEANS THAT THE SAME LINE WILL BE
! USED FOR THE NEXT PRINT STATEMENT.

TENS:
IF I=1 THEN ? #1,ORDINA$[J;1];SPACE(1);YLBL$(J);SPACE(1);A$;:GOTO THERE
IF I=25 THEN ? #1,A$:GOTO THERE
? #1,A$;

THERE:
NEXT I
NEXT J

GOSUB LABEL'X
! NOTE:DEPENDING ON THE CLASSIFICATION SCHEME NOT ALL OF THE FOLLOWING WILL
! BE USED. SOME MAY BE GROUPED INTO SNOW AND SOME MAY BE GROUPED INTO MIXED.
IF PT'IN=1 THEN PT'IN$="FROZEN"    !ORIGINAL ALTERNATIVE WAS SNOW
IF PT'IN=2 THEN PT'IN$="SNOW GRAINS"
IF PT'IN=3 THEN PT'IN$="ICE PELLETS"
IF PT'IN=4 THEN PT'IN$="FREEZING"   !ORIGINAL ALTERNATIVE WAS FREEZING RAIN
IF PT'IN=5 THEN PT'IN$="LIQUID"     !ORIGINAL ALTERNATIVE WAS RAIN
IF PT'IN=6 THEN PT'IN$="ICE PELLETS & SNOW (MIXED)"
IF PT'IN=7 THEN PT'IN$="FREEZING RAIN & SNOW (MIXED)"
IF PT'IN=8 THEN PT'IN$="RAIN & SNOW (MIXED)"
IF PT'IN=9 THEN PT'IN$="FREEZING RAIN & ICE PELLETS (MIXED)"
IF PT'IN=10 THEN PT'IN$="RAIN & ICE PELLETS (MIXED)"
IF PT'IN=11 THEN PT'IN$="FREEZING RAIN & ICE PEL. & SNOW (MIXED)"
IF PT'IN=12 THEN PT'IN$="RAIN & ICE PEL. & SNOW (MIXED)"
IF PT'IN=13 THEN PT'IN$="SNOW PELLETS"
IF PT'IN=14 THEN PT'IN$="RAIN & SNOW PELLETS (MIXED)"
IF PT'IN=15 THEN PT'IN$="FREEZING RAIN & SNOW GRAINS (MIXED)"
IF PT'IN=16 THEN PT'IN$="MIXED"
IF PT'IN=17 THEN PT'IN$="MISCELLANEOUS: SEE GROUPING SCHEME"
? #1,SPACE(19);ABSCIS$
```

APPENDIX A-(Continued)

```
? #1," "
? #1,"SAMPLE FREQUENCIES"
? #1," "
? #1,"STATION:";STA$;"/  PRECIPITATION TYPE: ";PT'IN$
? #1,"NUMBER OF HOURS NOT WITHIN ARRAY BOUNDARIES=";MISFIT
? #1, "TOTAL HOURS SEARCHED=";TOTAL'COUNT
? #1, "TOTAL HOURS OF PRECIPITATION TYPE=";PT'COUNT;" PT:";PT'IN
? #1,"GROUPING SCHEME: ";GROUP$
? #1, "MINIMUM ACCEPTABLE X=";XLOLIM-X'INC;", USING AN X-INCREMENT OF:";X'INC
? #1, "MINIMUM ACCEPTABLE Y=";YLOLIM-Y'INC;", USING A  Y-INCREMENT OF:";Y'INC
? #1, "PLOTTED VALUES ARE LESS THAN OR EQUAL TO COORDINATE VALUES."
IF KKK=1 THEN ? #1,"AT LEAST ONE VALUE IS BELOW LOWER LIMIT(S) OF MATRIX"
CLOSE #1
END

! THE REST OF THIS PROGRAM IS SUBROUTINES
LABEL'X:
    ! THIS IS SUBROUTINE LABEL'X
FOR RR=1 TO 4
    ! NOTE "4" MEANS THAT EACH LABEL CONTAINS 4 DIGITS
FOR R=1 TO 25
    ! NOTE EVERY OTHER LABEL IS BLANK
IF R=1 THEN PRINT #1,SPACE(7);XLBL$(R)[RR;1];SPACE(1);:GOTO BRNCH1
IF R=25 THEN PRINT #1,XLBL$(R)[RR;1]: GOTO BRNCH1
PRINT #1,XLBL$(R)[RR;1];SPACE(1);
BRNCH1:
NEXT R
NEXT RR
RETURN

PARA'METER:

! NOTE: AFTER THE X VALUE IS FOUND, IT SEARCHES FOR THE Y VALUE.
IF X'PAR$="TF"   THEN X=  TF-XLOLIM:GOTO YVAL
IF X'PAR$="DZ81" THEN X=DZ81-XLOLIM:GOTO YVAL
IF X'PAR$="DZ71" THEN X=DZ71-XLOLIM:GOTO YVAL
IF X'PAR$="DZ51" THEN X=DZ51-XLOLIM:GOTO YVAL
IF X'PAR$="DZ78" THEN X=DZ78-XLOLIM:GOTO YVAL
IF X'PAR$="DZ58" THEN X=DZ58-XLOLIM:GOTO YVAL
IF X'PAR$="DZ57" THEN X=DZ57-XLOLIM:GOTO YVAL
  YVAL:
IF Y'PAR$="TF"   THEN Y=  TF-YLOLIM:RETURN
IF Y'PAR$="DZ81" THEN Y=DZ81-YLOLIM:RETURN
IF Y'PAR$="DZ71" THEN Y=DZ71-YLOLIM:RETURN
IF Y'PAR$="DZ51" THEN Y=DZ51-YLOLIM:RETURN
IF Y'PAR$="DZ78" THEN Y=DZ78-YLOLIM:RETURN
IF Y'PAR$="DZ58" THEN Y=DZ58-YLOLIM:RETURN
IF Y'PAR$="DZ57" THEN Y=DZ57-YLOLIM:RETURN
PRINT "IF YOU'VER REACHED THIS STEP WITHOUT RETURNING"
PRINT "TO THE MAIN PROGRAM, YOU'RE IN TROUBLE":STOP

WORDS:
! NOTICE THAT ALL RESPECTIVE LABELS HAVE SAME # OF CHARACTERS IN STRING.
IF X'PAR$="TF"   THEN ABSCIS$=" TEMPERATURE (F)  "
IF X'PAR$="DZ81" THEN ABSCIS$="850-1000 MBS (GPM)"
IF X'PAR$="DZ71" THEN ABSCIS$="700-1000 MBS (GPM)"
IF X'PAR$="DZ51" THEN ABSCIS$="500-1000 MBS (GPM)"
IF X'PAR$="DZ78" THEN ABSCIS$=" 700-850 MBS (GPM)"
IF X'PAR$="DZ58" THEN ABSCIS$=" 500-850 MBS (GPM)"
IF X'PAR$="DZ57" THEN ABSCIS$=" 500-700 MBS (GPM)"
IF Y'PAR$="TF"   THEN ORDINA$="     )F( ERUTAREPMET    "
IF Y'PAR$="DZ81" THEN ORDINA$="      )MPG( SBM 0001-058   "
IF Y'PAR$="DZ71" THEN ORDINA$="      )MPG( SBM 0001-007   "
IF Y'PAR$="DZ51" THEN ORDINA$="      )MPG( SBM 0001-005   "
IF Y'PAR$="DZ78" THEN ORDINA$="      )MPG( SBM 058-007    "
IF Y'PAR$="DZ58" THEN ORDINA$="      )MPG( SBM 058-005    "
IF Y'PAR$="DZ57" THEN ORDINA$="      )MPG( SBM 007-005    "
RETURN
```

APPENDIX B-EXAMPLE OF SAMPLE DATA BASE

H8	H7	H5	PT	TF	H1	DZ81	DZ71	DZ51	DZ78	DZ58	DZ57
1211172											
1511	3077	5702	05	40	204	1307	2873	5498	1566	4191	2625
1511	3077	5701	05	40	202	1309	2875	5499	1566	4190	2624
1512	3077	5700	05	40	204	1308	2873	5496	1565	4188	2623
1513	3076	5698	05	40	213	1300	2863	5485	1563	4185	2622
1514	3076	5696	05	39	221	1293	2855	5475	1562	4182	2620
1515	3075	5695	05	39	222	1293	2853	5473	1560	4180	2620
1516	3074	5693	05	40	229	1287	2845	5464	1558	4177	2619
1517	3074	5691	10	39	232	1285	2842	5459	1557	4174	2617
1091272											
1498	3117	5790	05	42	142	1356	2975	5648	1619	4292	2673
1499	3118	5790	05	42	145	1354	2973	5645	1619	4291	2672
1500	3119	5790	05	41	151	1349	2968	5639	1619	4290	2671
1501	3120	5790	05	41	153	1348	2967	5637	1619	4289	2670
1101272											
1509	3127	5790	05	35	188	1321	2939	5602	1618	4281	2663
1510	3128	5790	05	34	190	1320	2938	5600	1618	4280	2662
1511	3129	5790	05	33	198	1313	2931	5592	1618	4279	2661
1512	3130	5790	05	32	207	1305	2923	5583	1618	4278	2660
1514	3133	5790	03	29	230	1284	2903	5560	1619	4276	2657
1515	3133	5790	04	29	225	1290	2908	5565	1618	4275	2657
1515	3134	5790	04	28	217	1298	2917	5573	1619	4275	2656
1516	3135	5790	04	27	230	1286	2905	5560	1619	4274	2655
1517	3135	5791	04	27	230	1287	2905	5561	1618	4274	2656
1517	3134	5791	04	27	236	1281	2898	5555	1617	4274	2657
1518	3134	5792	04	27	236	1282	2898	5556	1616	4274	2658
1518	3134	5793	04	27	234	1284	2900	5559	1616	4275	2659
1518	3133	5793	04	27	231	1287	2902	5562	1615	4275	2660
1519	3132	5794	04	28	226	1293	2906	5568	1613	4275	2662
1111272											
1519	3132	5795	04	28	217	1302	2915	5578	1613	4276	2663
1519	3131	5796	04	28	214	1305	2917	5582	1612	4277	2665
1518	3130	5797	04	29	211	1307	2919	5586	1612	4279	2667
1518	3129	5798	04	29	209	1309	2920	5589	1611	4280	2669
1518	3128	5799	04	28	208	1310	2920	5591	1610	4281	2671
1517	3127	5800	04	28	203	1314	2924	5597	1610	4283	2673
1516	3126	5801	04	28	200	1316	2926	5601	1610	4285	2675
1514	3126	5802	04	28	206	1308	2920	5596	1612	4288	2676
1512	3125	5803	04	29	211	1301	2914	5592	1613	4291	2678
1510	3124	5804	04	29	209	1301	2915	5595	1614	4294	2680
1507	3124	5804	04	30	203	1304	2921	5601	1617	4297	2680
1505	3123	5804	04	30	195	1310	2928	5609	1618	4299	2681
1502	3122	5804	04	31	184	1318	2938	5620	1620	4302	2682
1499	3121	5804	04	31	175	1324	2946	5629	1622	4305	2683
1496	3119	5804	04	31	168	1328	2951	5636	1623	4308	2685
1493	3118	5803	04	31	166	1327	2952	5637	1625	4310	2685
1490	3117	5802	04	31	163	1327	2954	5639	1627	4312	2685
1487	3115	5800	04	31	162	1325	2953	5638	1628	4313	2685
1484	3112	5797	04	31	159	1325	2953	5638	1628	4313	2685
1481	3109	5793	04	31	156	1325	2953	5637	1628	4312	2684
1478	3107	5789	04	31	151	1327	2956	5638	1629	4311	2682
1475	3104	5785	04	32	151	1324	2953	5634	1629	4310	2681
1473	3100	5781	04	32	144	1329	2956	5637	1627	4308	2681
1470	3097	5776	04	32	147	1323	2950	5629	1627	4306	2679
1121272											
1468	3094	5771	04	32	141	1327	2953	5630	1626	4303	2677
1467	3091	5767	04	32	149	1318	2942	5618	1624	4300	2676
1465	3088	5762	04	32	152	1313	2936	5610	1623	4297	2674
1465	3086	5758	04	32	152	1313	2934	5606	1621	4293	2672

BIBLIOGRAPHY

Albrecht, Bob; Finkel, Lercy; and Brown, Jerald R. Basic for Home Computers. New York: John Wiley & Sons, Inc., 1978.

Alpha Microsystems. AlphaBasic User's Manual. Version 3.3. North Irvine, Ca.: Alpha Micro, 1977.

Brelsford, William M., and Jones, Richard H. "Estimating Probabilities." Monthly Weather Review 95 (August 1967): 570-76.

Boyden, C.J. "A Comparison of Snow Predictors." The Meteorological Magazine 93 (December 1964): 353-65.

Carter, Gary M.; Dallavalle, J.Paul; Forst, Albert L.; and Klein, William H. "Improved Automated Surface Temperature Guidance." Monthly Weather Review 107 (October 1979): 1263-74.

Coan, James S. Basic BASIC. 2d ed. Rochelle Park, N.J.: Hayden Book Co., Inc., 1978.

Gellert, W.; Kustner, H.; Hellwich, M.; and Kastner, A., eds. "Calculus of Errors." The VNR Concise Encyclopedia of Mathematics. 1st American ed. New York: Van Nostrand Reinhold Co., 1977.

Huschke, Ralph E., ed. Glossary of Meteorology. Boston: American Meteorological Society, 1959: 2d printing with corrections, 1970.

Harms, Rheinhart W. "The Great Snowstorm of February 1973 over Georgia." Weatherwise 27 (October 1974): 192-98.

"Interpolation Formulae." The Universal Encyclopedia of Mathematics. New York: New American Library, 1964.

Kline, S.J., and McClintock, F.A. "Describing Uncertainties in Single-Sample Experiments." Mechanical Engineering, January 1953, pp. 3-8.

List, Robert J. Smithsonian Meteorological Tables. 6th rev. ed. Washington, D.C.: Smithsonian Institution Press, 1949.

Mullish, Henry. A Basic Approach to Basic. New York: John Wiley & Sons, Inc. 1976.

Saucier, Walter J. Principles of Meteorological Analysis. Chicago: University of Chicago Press, 1955.

"Snowstorm During the Night of April 25-26, 1950." Meteorological Magazine 79 (August 1950): 224-31.

Turabian, Kate L. A Manual for Writers of Term Papers, Theses, and Dissertations. 4th ed. Chicago: The University of Chicago Press, 1973.

U.S. Air Force. Air Weather Service (MAC) 6th Weather Wing. A Resumé on the State of the Art for Snow Forecasting, by Charles L. Brenton, Jr., Technical Note 73-6. Washington, D.C.: USAF Environmental Technical Applications Center, July 1973.

U.S. Air Force. Air Weather Service. Use of the Skew T, Log P Diagram in Analysis and Forecasting, A.W.S. Manual 105-124. Scott Air Force Base, Ill.: Headquarters Air Weather Service, 15 July 1969.

U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Weather Service. Automated Maximum/Minimum and 3-Hourly Surface Temperature Guidance, by Gary M. Carter and J. Paul Dallavale, Technical Procedures Bulletin No. 238. Silver Spring, Maryland: Techniques Development Laboratory, May 22, 1978.

U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Weather Service. Operational Probability of Frozen Precipitation (POF) Forecasts Based on Model Output Statistics, by Joseph R. Bocchieri, Technical Procedures Bulletin No. 146. Silver Spring, Maryland: Techniques Development Laboratory, August 28, 1975.

U.S. Department of Commerce. National Oceanic and Atmospheric Administration. National Weather Service. Operational Probability of Precipitation Type Forecasts Based on Model Output Statistics, by Joseph R. Bocchieri, Technical Procedures Bulletin No. 243. Silver Spring, Maryland: Techniques Development Laboratory, August 10, 1978.

U.S. Department of Commerce. Weather Bureau. Manual of Radiosonde Observations (WBAN) Circular P. 7th ed. Washington, D.C.: U.S. Government Printing Office, June 1957; reprint ed. with changes, April 1963.

U.S. Department of Commerce. Weather Bureau. Forecasting Maximum Maximum and Minimum Temperatures, by Woodrow W. Dickey, Donald L. Jorgensen, ed. Forecasting Guide No. 4. Washington, D.C.: Government Printing Office, March 1960.

U.S. Department of Commerce. Weather Bureau. The Prediction of Snow vs. Rain, by Samuel Penn, Jay S. Winston, ed. Forecasting Guide No. 2. Washington, D.C.: Government Printing Office, November 1957.

Wagner, James A. "Mean Temperature from 1000 MB to 500 MB as a Predictor of Precipitation Type." Bulletin American Meteorological Society 38 (December 1957): 584-90.